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TECHNICAL REPORT NO. 2

AUGUST 1954

PROJECT SCUD
CONTRACT No. Nonr 285 (09)

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THE OFFICE OF NAVAL RESEARCH

RESEARCH DIVISION

COLLEGE OF ENGINEERING

NEW YORK UNIVERSITY

TECHNICAL REPORT NO. 2

AUGUST 1954

AN EXPERIMENT IN LARGE SCALE CLOUD SEEDING IN THE EAST COASTAL REGION OF THE UNITED STATES

ANALYSIS OF EXPERIMENTAL DATA
FOR [illegible]ARY-APRIL 1953 AND
DECE[illegible] 1953 - APRIL 1954

PROJECT SCUD
CONTRACT No. Nonr 285 (09)

SPONSORED BY
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Abstract

The project was designed to find out if presently available cloud seeding techniques are capable of producing large scale weather modifications, particularly with respect to cyclone development in the east coastal region of the United States.

A randomized block design was used in the experiment. Of each pair of weather situations selected for seeding, one case was seeded and the other was not. The method of analysis of covariance was then applied to the problem of determining the confidence with which differences between the seeded and unseeded samples could be attributed to the seeding.

Seeding was conducted both by ground operated silver iodide smoke generators and by aircraft dispensing dry ice.

Between January and April 1953 twenty-one (21) cases were collected of which eleven (11) were seeded and ten (10) were not. Between December 1953 and April 1954 sixteen (16) cases were collected of which eight (8) were seeded and eight (8) were not. The seeding technique used in the second experiment was somewhat different from that used in the first experiment.

Pressure changes and precipitation were used as test variates in the statistical analysis and confidence limits on the differences between the test variates for the seeded and unseeded samples were obtained.

With the data available thus far we cannot reject the hypothesis that seeding has no effect as far as the large scale test variates employed in the experiment are concerned.

Acknowledgments

Flight operations during the period December 1953 - April 1954 were carried out by Navy Airborne Early Warning Squadron Four under the command of Cdr. L. V. Dachs at the Naval Air Station, Jacksonville, Florida.

Liaison with the squadron and with the operators of the silver iodide generators was effected through the Navy Project Officer at the Naval Air Station, Norfolk, Va., Cdr. Charles E. Tilden, and his assistant AGC Howard J. Wells. Cdr. Tilden and AGC Wells also provided for the maintenance and supply of the smoke generators.

The statistical analysis of the experimental data was done principally by Drs. Robert Hooke, Forman S. Acton and Richard Link of the Analytical Research Group, Princeton, N.J. in close cooperation with Dr. John W. Tukey of Princeton University.

The following employees of New York University participated in the project:

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	William Bornstein
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	Rudolph Perchal
	Roy E. Peterson
	Gunther Reiss
Research Aide	Mrs. Jane Carr
Laboratory Technician	Miss Joan Cipley
Secretary	Mrs. Augusta Taback
Consultant on Instrumentation	Asst. Prof. Richard J. Schotland

Precipitation data for the United States were provided by the National Weather Records Center, Asheville, N.C. through the cooperation of Mr. Leslie Smith, Supervisor.

Chapter I. Introduction

The first experiment in large scale cloud seeding in the eastern United States was conducted by Project SCUD between January and April 1953. The results of this experiment (hereafter referred to as ONE) have been given in the first technical report of this project ("An Experiment in Large Scale Cloud Seeding in the East Coastal Region of the United States", Technical Report No. 1, Contract No. Nonr-285 (09). October 1953), hereafter referred to as No. 1.

The design of the experiment, the experimental technique and the statistical analysis of the first experiment have been described in No. 1. The basic conclusion presented in No. 1 was that the twenty-one experimental cases did not provide sufficient information to enable us to answer the question as to the efficacy of cloud seeding with respect to large scale weather modification. Indeed it was not expected that one season of seeding would provide such information.

The first experiment did provide confidence limits on the effects of seeding. It was expected that further experimentation would reduce the confidence intervals so that ultimately it might be possible to say either that seeding has an effect of at least a certain magnitude or that its effect is too small to be of interest.

The second experiment (hereafter referred to as TWO) was conducted by Project SCUD between December 1953 and April 1954. The analysis of the data for this experiment and the analysis of the combined data for ONE and TWO are presented in this report.

The basic design of experiment TWO was the same as that of ONE. The method of selection of cases and the method of undisclosed randomization in blocks of two (see No. 1) was unchanged. As in ONE, seeding in TWO was carried out simultaneously with dry ice released from aircraft and silver iodide smoke released from seventeen dispersed ground generators. The seeding period was of twelve hours duration beginning at a designated zero hour. As in ONE, one member of each pair of cases selected was seeded (Able cases) and the other was not (Baker cases). In the Able cases seeding with silver iodide was conducted without interruption for twelve hours while the dry ice seeding was conducted within this period for a shorter time. The solution employed in the silver iodide generators was the same in TWO as in ONE and the number and location of the generators were unchanged.

On the basis of experience acquired in ONE several changes were made in the experimental technique and in the statistical procedures prior to the beginning of TWO. These changes were made at the expense of homogeneity so that the combination of data for ONE and TWO may be a questionable procedure. However, it was felt that salvaging the data of ONE was less important than improving the design of the experiment. It was anticipated at the beginning of ONE that some modification of the experiment would be necessary.

The following changes in experimental technique were made in TWO:

1. Increase of the dry ice seeding rate. Prior to TWO we were advised by Drs. aufm Kampe and Weickmann of the Evans Signal Laboratory, Belmar, N. J. that the seeding rate of one pound per mile used in ONE was probably inadequate (see Chapter VIII in No. 1). A dispensing rate of at least five pounds per mile was recommended. Although we would have preferred a higher rate, the rate of five pounds per mile was adopted in TWO as a compromise between our wishes and the load limitations of the airplanes.

2. Exclusive use of P2V airplanes. The seeding in ONE was conducted partly by P4Y and partly by P2V aircraft. The former were rather unsatisfactory, mainly because of their low service ceiling, and were ultimately replaced by the P2V aircraft. In TWO all seeding flights were conducted by P2V airplanes with a resulting increase in the height of the dispensing level and a reduction of the flight level temperature.

3. Increase of total amount of dry ice dispensed. In ONE each of the three aircraft participating in an Able flight carried about 1000 pounds of dry ice. In TWO not only was the dispensing rate increased fivefold, but the load of each aircraft was increased to about 2500 pounds of dry ice. Thus in TWO it was possible to dispense a maximum of 7500 pounds of dry ice at the rate of five pounds per mile as compared with 3000 pounds at a rate of one pound per mile in ONE. (A heavy duty dry ice crusher was purchased for this operation from the Stimmel Winch Co., Long Island City, New York. This crusher is operated by a 3 H.P. motor and can accept full 50 pound blocks of dry ice without precrushing. Each block is crushed to the desired size in about five seconds. The cost of the crusher, including motor and stand, was $422.00.)

4. Selection of target area. In ONE the seeding tracks selected by the forecasters at New York University were approximately 1000 miles long and could extend over any portion of the east coastal region. The extent of the seeding tracks introduced certain difficulties

into the analysis of the experiment, notably in the analysis of the rainfall data. Therefore, in TWO target areas were employed rather than prescribed tracks. The east coastal region was divided into six overlapping target areas (see figures 1 and 2) numbered 1 to 6. Three standard tracks (designated red, blue and green respectively for the southern, central and northern track in each area) were established for the target areas. The zero hour and target areas were given in each case in the instructions from N.Y.U. If the Navy Project Officer at Norfolk determined that the case selected was to be seeded (Able), one plane of the squadron was dispatched on each of the three tracks in the designated target area. In Baker cases a reconnaissance flight was flown on the Blue track. The length of each of the tracks varied between 323 and 645 miles with an average length of 522 miles.

5. <u>Air to ground communication</u>. One of the deficiencies of ONE was the inability of the project personnel to communicate with the aircraft during a mission. Had we been able to establish communication we might have been able on occasion to redirect the airplanes to areas more favorable for seeding operations. In TWO a procedure was established for communicating with the aircraft via commercial marine radio-telephone. The procedure was for the airplane on the blue track to initiate a call to N.Y.U. when the plane was within one hour's flight of the target area. (The blue track was used so that the N.Y.U. personnel would not learn whether the flight was an Able or Baker mission.) At that time special

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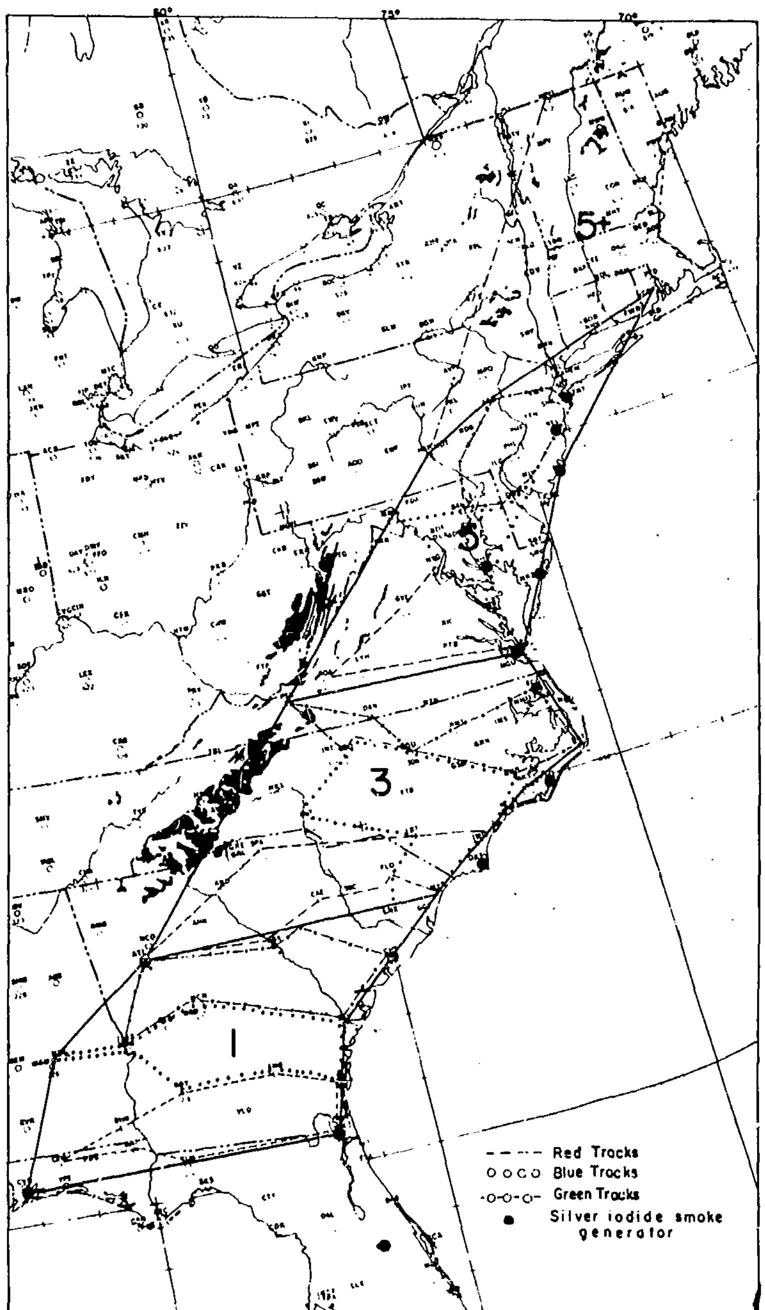

Figure 1 Map of target areas 1, 3, and 5 showing tracks and locations of ground generators.

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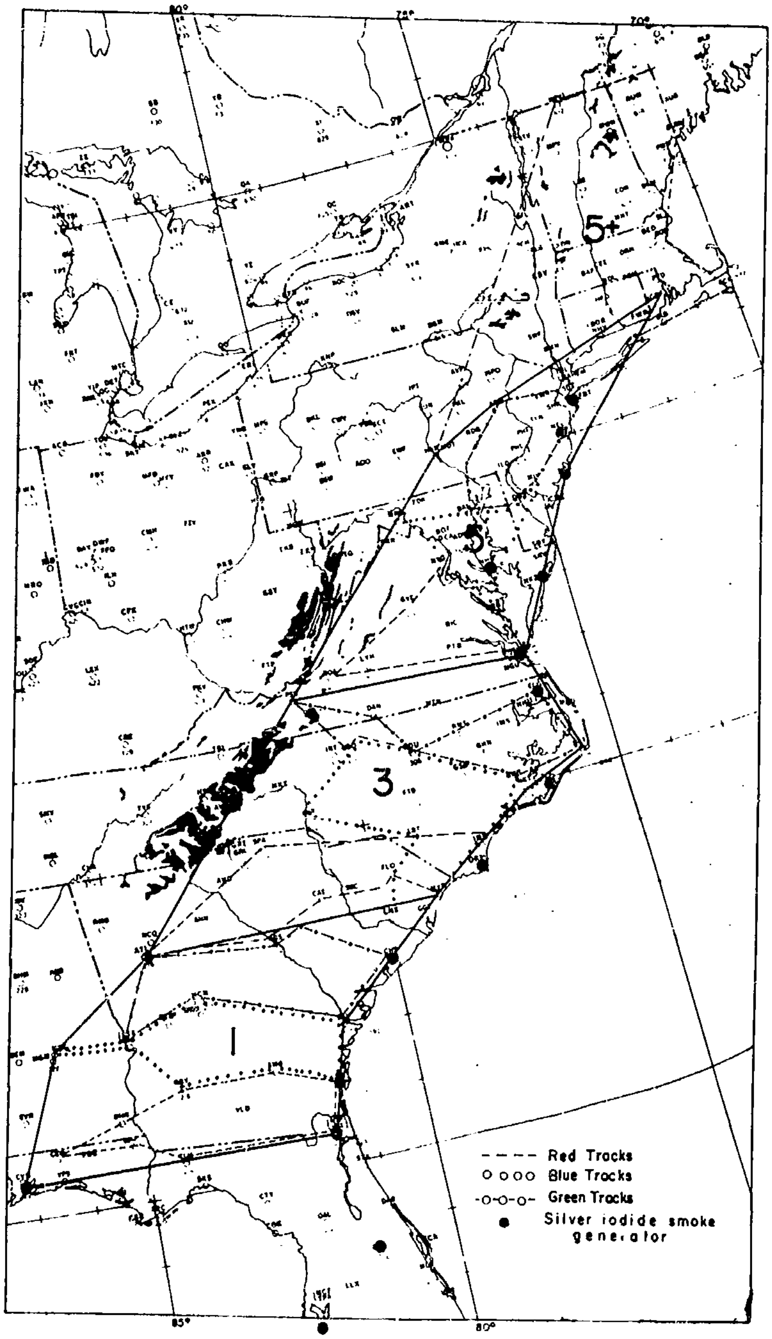

Figure 1 - Map of target areas 1, 3, and 5 showing tracks and locations of ground generators.

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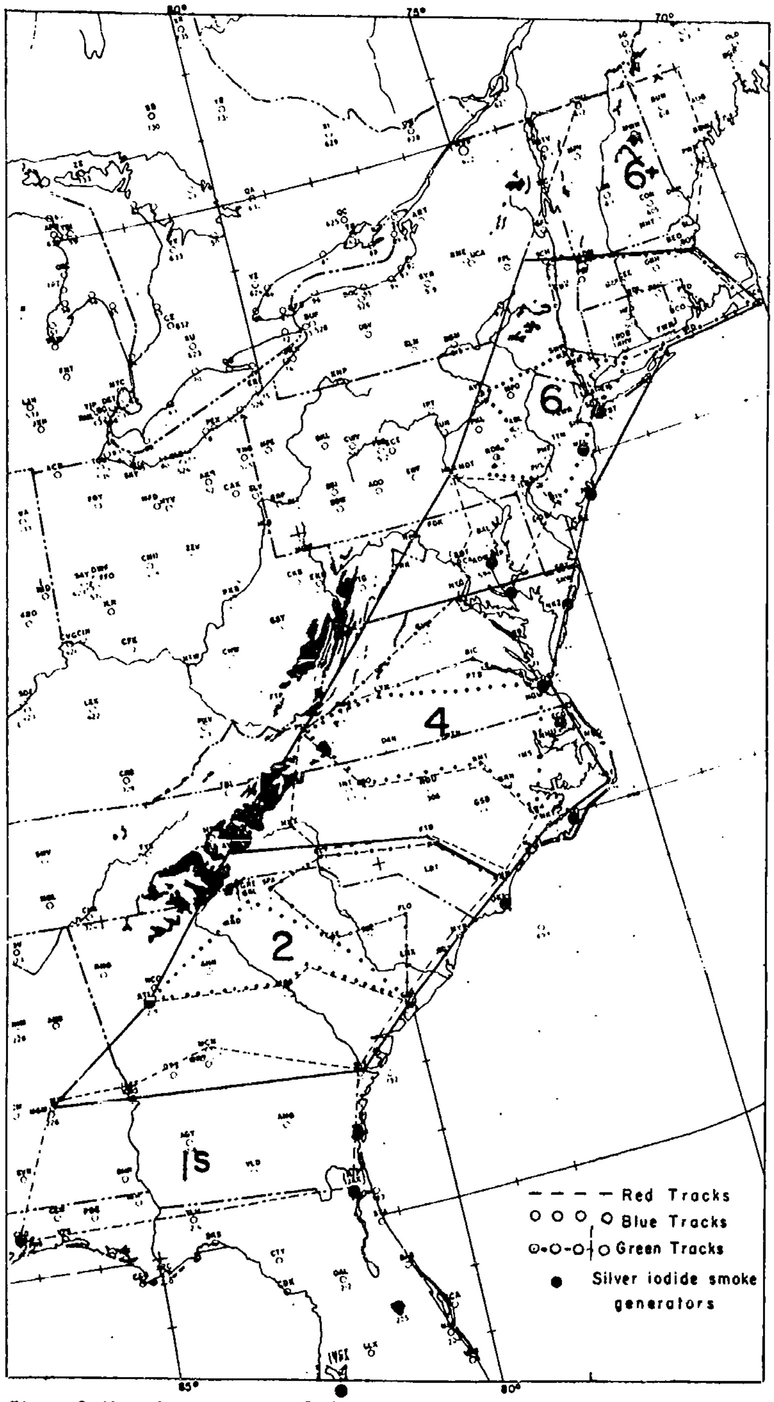

Figure 2: Map of target areas 2, 4 and 6 showing tracks and locations of ground generators.

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procedures could be recommended. For example, the crew might be advised to concentrate its activities in one corner of the target area. (The target area itself could not be changed because of prior agreements with the Civil Aeronautics Authority. Through these agreements the squadron was able to obtain preferred altitudes in the target areas, but only if flight plans were filed several hours before takeoff.) The crew could also initiate additional calls after entering the target area if advice was required from the N.Y.U. forecasters.

The following changes in statistical procedure were also established prior to the beginning of experiment TWO.

1. <u>Test variates</u>: In ONE the primary variates used to test the significance of the difference between the means of the Able and Baker groups were (see No. 1)

   R_1: The average 24 hour precipitation in the east coastal region (region Ia) beginning at zero hour.

   R_2: The avarage 24-hour precipitation in the Nova Scotia-Newfoundland - Labrador region (region IIa) beginning at zero-plus-twelve hours.

   P_1: The average 24-hour pressure change at sea level beginning at zero hour in the east coastal and adjacent ocean region (region I).

   P_2: The average 24 hour sea level pressure change beginning at zero-plus-twelve hours in the region northeast of region I (region II).

These variates were retained in the design of TWO However, the following variates were also included in the design:

R_t : The average 24-hour precipitation in the target area beginning at zero hour.

P_{m1} : The maximum 24-hour decrease of sea level pressure in region I in the period beginning zero hour.

P_{m2} : The maximum 24-hour decrease of sea level pressure in region II in the period beginning at zero-hour-plus twelve hours.

For reasons which were explained in No 1, we employed logarithms of the precipitation in the statistical analysis of TWO as we did in ONE. In each case R_1, R_2 and R_t were determined by essentially an arithmetic averaging process (described more fully in the next chapter), and the logarithms of these individual case averages were employed for the statistical analysis. Thus the statistical analysis was applied in effect to geometrical means rather than to arithmetic means of the precipitation.

2. Covariates: The primary covariate employed in the design of ONE to adjust the data for natural differences between the Able and Baker samples was the east coastal meridional circulation index, M (see No. 1). In the section on Afterthoughts in No. 1 mention was also made of the use of a covariate T, which is a measure of the divergence of the flux of water vapor in the east coastal region, and also of the use of P_1 as a covariate for the analysis of P_2. Both of these quantities as well as M were incorporated into the design of TWO.

An additional covariate for the analysis of precipitation was adopted before the beginning of TWO. This quantity, which we designated L, is a measure of the position of the cyclone center at zero hour with respect to the east coastal region. A straight line was drawn on our conformal conic map from Burwood, La. to Nantucket, Mass. and a perpendicular was drawn to this line from the southern-most surface cyclone center east of longitude 95° W and west of 65° W. The quantity L is the distance, in tens of miles, from Burwood to the intersection of the perpendicular. If no cyclone center could be found on the surface map in this region, the katallobaric center was used if the pressure tendency was less than -3.5 mb per 3 hours. If such a center did not exist at zero hour, the total distance from Burwood to Nantucket was entered for L.

The covariate L was designed to adjust R_1 for the effects of varying rainfall distribution and duration. A small value of L indicates that the cyclone or katallobaric center is in the southern part of the east coastal region at zero hour. Such a system will normally move northeastward and will tend to produce precipitation throughout the region and for a relatively long time. Thus low values of L should be associated with high values of R_1. Conversely, a high value of L indicates that the center is already in the northern part of the region and will shortly move out of the region with the result that the precipitation will tend to occur mainly in the north and the duration of precipitation in the region will be short.

A modified form of divergence of the water vapor flux, T, was used as a covariate for the target area precipitation, R_t. This quantity, T_t, is the partial value of T corresponding to the southern or northern portion of the region depending on the location of the target area. For target areas 1, 2 and 3, T_t was calculated for the polygon with vertices at Burrwood,Nashville, Hatteras and Tampa while for target areas 4, 5 and 6 (the northern group) we used Nashville, Hatteras, Nantucket and Pittsburgh.

The importance of covariates lies in their double function in the statistical analysis. On the one hand the covariates provide some insurance against possible bias in the experiment which may result from inherent non-treatment differences between the Able and Baker samples. On the other hand the covariates help to minimize the residual (or error) variance and contribute to an increase in the sensitivity of the experiment.

3. Control Areas: The use of a dispersed network of silver iodide generators made it impossible for us to use a control area method in the analysis of the experiment since no part of the east coastal region could really be considered as unseeded in the Able cases. However, the redesign of the experiment and the employment of target areas did permit us to begin a subsidiary experiment this year.

The situations selected for seeding were all cases of rather widespread cyclonic precipitation. Thus, in general, suitable seeding conditions existed not only in the target area but also around the target areas, and in particular to the south of the target area.

The dry ice seeding was conducted under conditions of southwesterly flow at the seeding level so that in Able cases no dry ice fell or was transported over the areas south of the target areas. However, these areas were seeded with silver iodide as was the target area itself. We therefore considered the area adjacent to and south of the target area as a control area in the sense that it was seeded only with silver iodide whereas the target area was seeded with both silver iodide and dry ice. (For target area number 4, the control area was number 2 in figure 2, etc.)

Our objective in using these control areas was the following: If a treatment effect were discovered we might be able to determine from an analysis of the target area precipitation (R_t) and the control area precipitation (R_c) whether the effect was due to seeding with silver iodide alone or to seeding with both silver iodide and dry ice simultaneously. If the latter proved to be the case, we could then redesign the experiment to determine if the silver iodide is necessary at all.

Unfortunately, the control areas were seeded on two occasions when the dry ice had to be jettisoned for reasons of flight safety. Since only six uncontaminated cases remained, no attempt was made this year to analyze the control area data. It was obvious from the sample variance that these six cases would provide very little information.

The observational and reporting program of the flight aerologists was altered in TWO in the following respects:

1. 35 mm Kodachrome cloud photographs were obtained as well as black and white photographs with the Fairchild K-20 camera. These photographs are not included in this report but will be made the subject of a separate analysis which we hope to report on at a later date.
2. A spring operated cloud sampler was constructed for the purpose of determining the nature of the cloud particles. In particular we wished to know whether the cloud particles were ice crystals or liquid water drops. The cloud sampler employs a plastic cylinder mounted on a spring operated rod which permits brief exposure of the cylinder in the cloud. The cylinder is coated with a liquid plastic (clear "Cutex" nail polish) which hardens shortly after exposure and retains an impression of the cloud particle. The sampler was not available for all of TWO and there was some difficulty in

analyzing the samples that were obtained due to the difficulty of viewing a cylindrical surface under the microscope, the occurence of impact shattering and contamination of the slide with dirt. No discussion of the results obtained with the sampler are included in this report.

3. The flight aerologists constructed cloud cross-sections for all flights. These cross-sections are presented in the Appendix to this report together with the zero hour and zero-plus-24 hour surface weather maps.

In the course of the two experiments we dispensed more than 30 tons of dry ice and more than 1000 gallons of silver iodide solution. More than 250 pounds of silver iodide were vaporized and about 7 tons of propane were consumed in the process.

The aircraft flew more than 490 hours and collected more than 325 cloud photographs, both in black-and-white and in color.

Chapter II. Data

The complete tabulation of data for experiments ONE and TWO is given in this chapter. The symbols have been defined in the previous chapter.

The areas Ia and IIa for which the precipitation amounts R_1 and R_2 were computed are each approximately 300,000 square miles. In ONE the isohyetal technique was applied to synoptic map reports to obtain the integrated precipitation R_1 and R_2 over these areas. In TWO the same technique was used for R_2. However, R_1 was computed by a different technique which is described below. This technique is also being used to recompute R_1 for ONE. At the present writing, however, this last computation has not been completed and the values of R_1 given for ONE are the values based on the isohyetal technique.

To obtain R_1 we divided area Ia into "squares" with sides 1/2 degree of latitude and 1/2 degree of longitude. It was also divided into target areas (see figures 1 and 2). Target areas 1, 3 and 5 cover almost all of Ia. By adding the area designated 5+, we were able to cover Ia completely. Alternatively, we can divide Ia into three target areas, 2, 4 and 6 plus two supplementary areas, Is and 6+.

In order to obtain a uniform distribution of raingages, no more than one station was used in each of the 1/2 degree "squares". The number of squares in the target areas ranged from 59 in area 6 to 77 in area 3. (The size of the individual target areas ranged from 58,000 square miles in area 6 to 79,000 square miles in area 3.)

The six-hourly precipitation amounts were provided by the National Weather Records Center at Asheville, N.C. for the 270 raingage stations used in the computation. The six-hourly periods began at zero-minus-6 hours and ended at zero-plus-24 hours. From these data we were able to obtain the rainfall prior to seeding, the 24-hour rainfall amounts corresponding to R_1 and R_t and the trend of the precipitation.

Arithmetic means of the precipitation amounts in each target area and supplementary area were computed for each case. Two separate computations of R_1 were made for each case by combining first areas 1, 3, 5 and 5+ and then areas 1s, 2, 4, 6 and 6+. In combining the areas an adjustment was made for the latitude to correct for the effect of variation in the areas of the 1/2 degree squares. The two estimates which differed only slightly in the third decimal place, were averaged to obtain R_1.

The quantities P_{m1} and P_{m2} were introduced because we were not satisfied that P_1 and P_2 were suitable measures of cyclonic development. In particular, it was felt that intense deepening could occur in regions I or II but this deepening could be counteracted by simultaneous anticyclogenesis in another part of the same region with the result that P_1 or P_2 might be zero or positive. This difficulty is avoided by using the maximum pressure decrease rather than the average pressure change. P_{m1} and P_{m2} were also obtained and tabulated for experiment ONE although they were not included in the original experimental design.

The quantities R_t and R_c (see Chap. I) are tabulated only for TWO since they cannot be defined for experiment ONE.

The precipitation amounts in Table 1 are in inches and the pressure changes are in millibars. The covariates M, T and Tt are expressed merely as relative numbers with no dimensional significance. L is given in tens of miles.

The 6-hourly precipitation amounts in experiment TWO are shown in table 2 for region Ia and the target areas.

Table 1. Test variates and covariates for experiments ONE and TWO.

No.	Zero hour/Date	Type	Target Area	R_1	R_2	R_t	R_c	P_1
				Experiment ONE				
1	1230/ 9 Jan. 1953	A		.498	.011			-2.8
2	0630/18 Jan. 53	B		.339	.016			-9.9
3	1230/21 Jan. 53	B		.188	.063			-2.1
4	0030/24 Jan. 53	A		.603	.721			-16.6
5	0630/ 1 Feb. 53	A		.021	.108			+3.5
6	0630/ 3 Feb. 53	B		.081	.086			-9.6
7	1830/ 6 Feb. 53	B		.519	.102			-5.8
8	0630/12 Feb. 53	A		.175	.006			-7.9
9	0630/15 Feb. 53	B		.738	.499			-8.7
10	1830/20 Feb. 53	A		.417	.200			-9.8
11	1230/25 Feb. 53	B		.138	.020			-3.1
12	1830/ 3 Mar. 53	A		.441	.439			-16.3
13	1230/13 Mar. 53	A		.180	.574			-4.2
14	1230/15 Mar. 53	B		.435	.137			-2.7
15	1830/18 Mar. 53	A		.178	.013			-3.1
16	1830/23 Mar. 53	B		.423	.062			-6.0
17	1830/ 1 Apr. 53	B		.072	.167			-0.9
18	1830/ 6 Apr. 53	A		.715	.160			-5.3
19	1830/10 Apr. 53	B		.075	.113			+1.4
20	0630/16 Apr. 53	A		.205	.066			-2.6
21	1230/18 Apr. 53	A		.260	.031			-4.6
				Experiment TWO				
22	1830/ 4 Dec. 53	A	4	.362	.426	.201	.393	-2.22
23	1830/ 9 Dec. 53	B	4	.374	.757	.358	.264	-11.05
24	1230/12 Dec. 53	A	2	.454	.133	.416	.422	-8.34
25	1830/10 Jan. 54	B	5	.364	.101	.539	.405	-5.52
26	1230/15 Jan. 54	B	5	.598	.059	.461	1.373	-13.39
27	1230/21 Jan. 54	A	4	.316	.033	.689	.451	+4.47
28	1830/27 Jan. 54	B	6	.089	.271	.216	.001	-3.95
29	1830/11 Feb. 54	A	4	.020	.198	.005	.047	+9.46
30	1830/20 Feb. 54	A	4	.497	.040	1.022	.661	-6.40
31	1830/24 Feb. 54	B	2	.192	.191	.110	.150	-5.79
32	1230/26 Feb. 54	A	6	.057	.197	.146	.002	+5.17
33	1230/ 1 Mar. 54	B	6	.232	.096	.689	.209	+5.87
34	1830/13 Mar. 54	A	5	.619	.130	.664	.892	-13.14
35	1830/19 Mar. 54	B	3	.563	.362	.497	.324	-11.15
36	1230/30 Mar. 54	B	6	.063	.028	.050	.168	+4.77
37	0630/28 Apr. 54	A	6	.117	.007	.172	.075	+2.75

Table 1. Test Variates and covariates for experiment ONE and TWO.

No.	Type	P_2	P_{m1}	P_{m2}	M	T	T_t	L
Experiment ONE								
1	A	-6.7	-9.0	-19.9	87	961		31
2	B	-12.6	-22.8	-23.8	63	269		81
3	B	-11.0	-31.0	-31.7	25	-699		65
4	A	-17.7	-31.0	-33.0	115	1203		56
5	A	+4.2	-20.8	-26.8	37	-259		135
6	B	-7.1	-28.5	-27.9	10	-279		53
7	B	-5.1	-12.2	-16.5	75	654		65
8	A	-2.9	-25.5	-17.5	28	402		105
9	B	-15.5	-41.3	-45.4	90	329		38
10	A	-26.1	-33.0	-50.2	71	1572		77
11	B	+0.9	-13.7	-16.8	-7	-97		23
12	A	-26.1	-38.7	-43.1	52	1156		33
13	A	-8.9	-19.3	-30.5	24	-122		107
14	B	-4.0	-14.5	-15.1	51	312		76
15	A	+1.7	-14.5	-10.0	30	798		77
16	B	+3.3	-13.8	-12.4	53	670		48
17	B	+0.3	-10.5	-7.8	17	-40		88
18	A	-2.4	-17.0	-24.0	47	1173		36
19	B	-4.7	-9.3	-23.5	44	-620		89
20	A	-1.4	-18.1	-22.0	57	-383		97
21	A	-2.6	-12.4	-14.5	43	709		30
Experiment TWO								
22	A	-9.60	-19.9	-33.5	99	140	100	65
23	B	-16.70	-28.3	-43.5	83	320	120	28
24	A	-3.53	-22.0	-17.0	58	411	312	28
25	B	-3.95	-14.5	-23.3	51	880	195	30
26	B	-13.84	-20.2	-23.6	19	938	340	136
27	A	+9.56	-9.8	-6.3	32	-450	-400	136
28	B	-6.48	-25.3	-22.5	27	-1187	-792	105
29	A	+2.87	-17.8	-18.5	-2	-845	-495	87
30	A	-5.55	-16.0	-16.0	91	1189	600	36
31	B	-8.23	-20.1	-20.0	44	-42	-28	34
32	A	+2.72	-8.8	-14.7	48	-91	193	98
33	B	-4.30	-12.7	-13.7	113	-839	39	90
34	A	-11.85	-30.7	-34.5	55	365	125	69
35	B	-7.39	-26.3	-26.0	52	997	327	49
36	B	+3.70	-2.7	-11.1	15	-480	-380	104
37	A	+5.90	-2.5	-4.7	1	338	301	106

C O N F I D E N T I A L

Table 1 Test Variates and covariates for experiment ONE and TWO

Experiment (Type)	R_1	R_2	R_t	R_c	P_1	P_2	P_{m1}	P_{m2}	M	T	T_t	L
Arithmetic Means												
ONE (A)	.336	.212			-6.35	-8.08	-21.75	-26.50	53.7	655		71
ONE (B)	.301	.127			-4.74	-5.57	-19.76	-22.09	42.1	50		68
TWO (A)	.305	.146	.414	.368	-1.03	-1.19	-15.94	-18.15	47.7	132	92	78
TWO (B)	.309	.233	.365	.362	-5.03	-7.15	-18.76	-22.96	50.5	73	-18	72
ONE and TWO (A)	.322	.184			-4.11	-5.18	-19.30	-22.98	51.3	435		74
ONE and TWO (B)	.305	.174			-4.87	-6.27	-19.31	-22.48	45.8	60		67

C O N F I D E N T I A L

Table 2 Six-hourly and 24-hourly precipitation amounts in region Ia and in target areas. Experiment TWO.

Case No.	Type	Target Area	Region Ia 0-6	0+6	6+12	12+18	18+24	0+24	Target Area 0-6	0+6	6+12	12+18	18+24	0+24
22	A	4	.186	.178	.082	.102	.001	.362	.150	.157	.047	.006	.001	.201
23	B	4	.069	.091	.128	.130	.025	.374	.130	.102	.166	.068	.016	.356
24	A	2	.155	.232	.151	.061	.011	.454	.416	.330	.041	.029	.012	.416
25	B	5	.016	.074	.134	.082	.075	.364	.047	.059	.240	.207	.036	.539
26	B	5	.040	.032	.050	.227	.289	.598	.024	.025	.043	.207	.187	.461
27	A	4	.129	.043	.009	.068	.197	.316	.271	.030	.003	.114	.542	.689
28	B	6	.039	.030	.038	.016	.005	.089	.028	.078	.100	.032	.005	.216
29	A	4	.008	.017	.003	.000	.000	.020	.001	.005	.000	.000	.000	.005
30	A	4	.117	.125	.085	.127	.161	.497	.094	.145	.201	.304	.362	1.022
31	B	2	.070	.068	.046	.040	.039	.192	.099	.076	.034	.001	.000	.110
32	A	6	.000	.011	.024	.020	.003	.057	.001	.046	.077	.023	.002	.146
33	B	6	.161	.102	.078	.040	.012	.232	.121	.249	.319	.120	.001	.689
34	A	5	.043	.085	.218	.214	.103	.619	.151	.065	.050	.347	.195	.664
35	B	3	.236	.210	.159	.157	.028	.563	.200	.334	.131	.028	.000	.497
36	B	6	.068	.010	.003	.017	.033	.063	.024	.004	.001	.022	.024	.050
37	A	6	.082	.051	.021	.028	.018	.117	.204	.113	.050	.050	.001	.172

Arithmetic Means

A	.103	.093	.074	.078	.062	.305	.161	.111	.059	.109	.139	.414
B	.087	.077	.080	.089	.063	.309	.084	.116	.129	.086	.034	.365
A + B	.095	.085	.077	.084	.063	.307	.123	.114	.094	.098	.087	.390

C O N F I D E N T I A L

Chapter III. Synoptic Analysis

A convenient device for representing the differences between the Able and Baker samples is the composite map. The composite map has the advantage over the tabular presentation of data of showing the spatial distribution of the test variates in the two samples and may reveal sample differences which are not evident from the table of data.

The interpretation of composite maps is subjective and cannot, in itself, provide proof one way or the other with regard to the seeding problem. Of course, any differences between the Able and Baker samples which appear in the composite maps may be tested for significance by statistical methods. However, since the tests must be applied to variates which are derived from the test data after the conclusion of the experiment, the results of such tests should carry little weight in themselves.

Figures 3 and 4 show the distribution of the average precipitation in the twenty-four hours following zero hour along the east coast (region Ia) for the nineteen Able and eighteen Baker cases of experiments ONE and TWO. These figures may be compared with the corresponding maps for experiment ONE (Figs. 13 and 14 in No. 1). In ONE the maxima in the northeast were 0.78 and 0.58 inches for the Able and Baker groups respectively. In the ONE-plus-TWO data the maxima are 0.59 and 0.52 inches for Able and Baker groups respectively. In general it can be seen that increasing the sample size from 21 to 37 cases has had the effect of reducing considerably the differences between the Able and Baker composite maps.

Figure 5 shows the distribution of the ratio of mean Able to mean Baker precipitation for all thirty-seven cases. The fact that the ratio is greater than one in some areas and less than one in others does not in itself signify anything.

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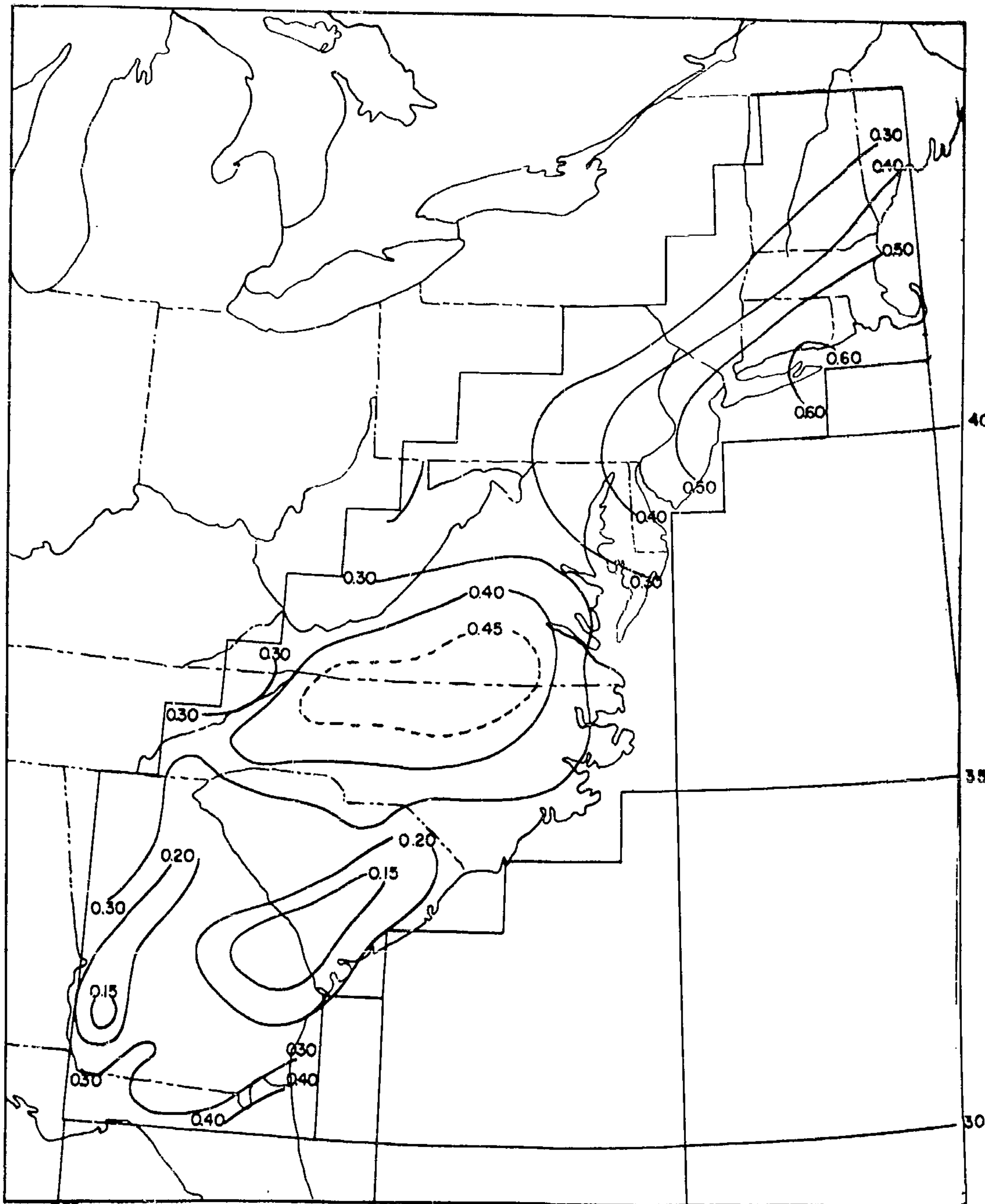

Fig. 3. Average 24-hour precipitation, beginning at zero hour for 19 Able (seeded) cases.

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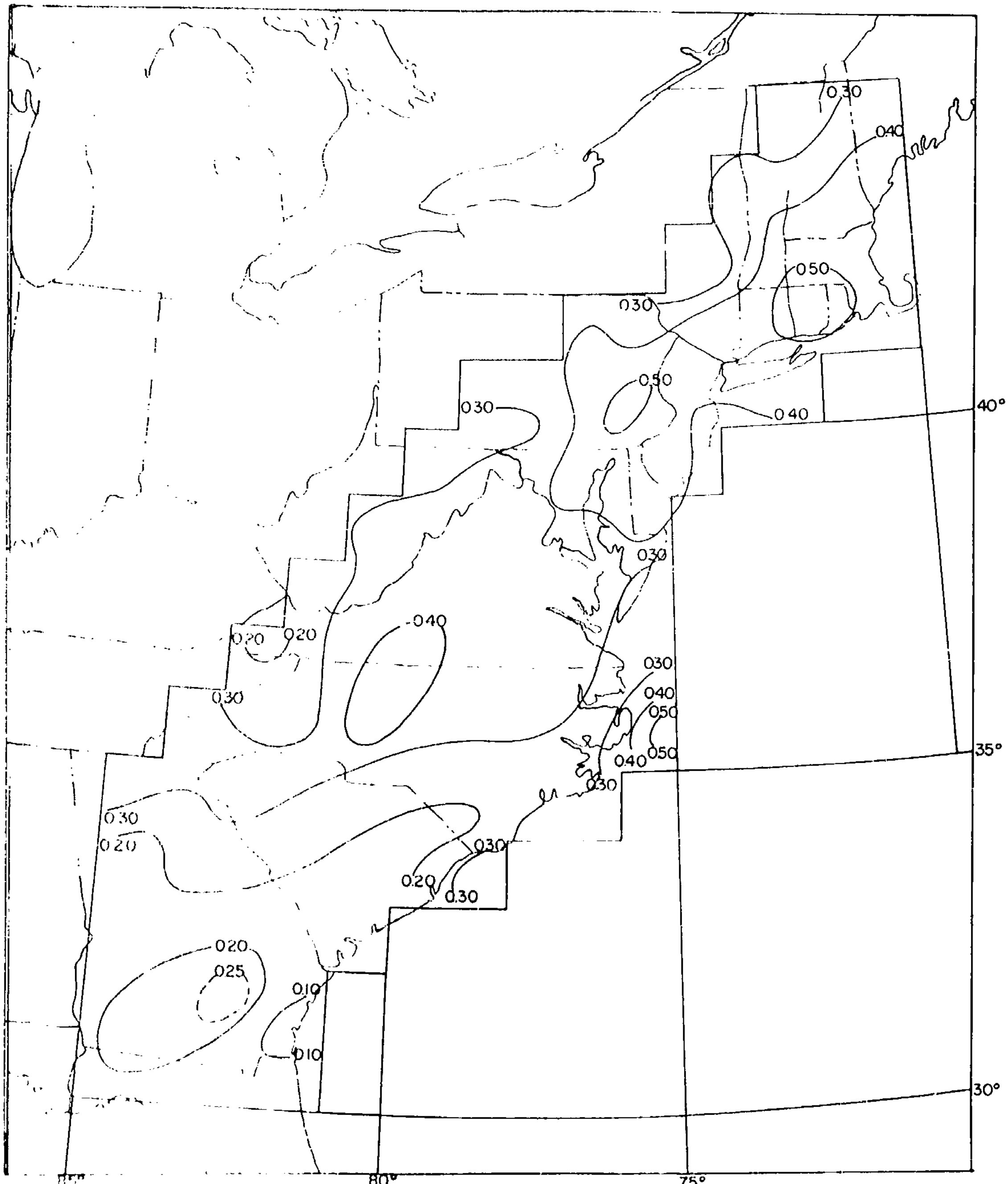

Fig 4 Average 24 hour precipitation, beginning at zero hour, for 18 Baker (unseeded) cases.

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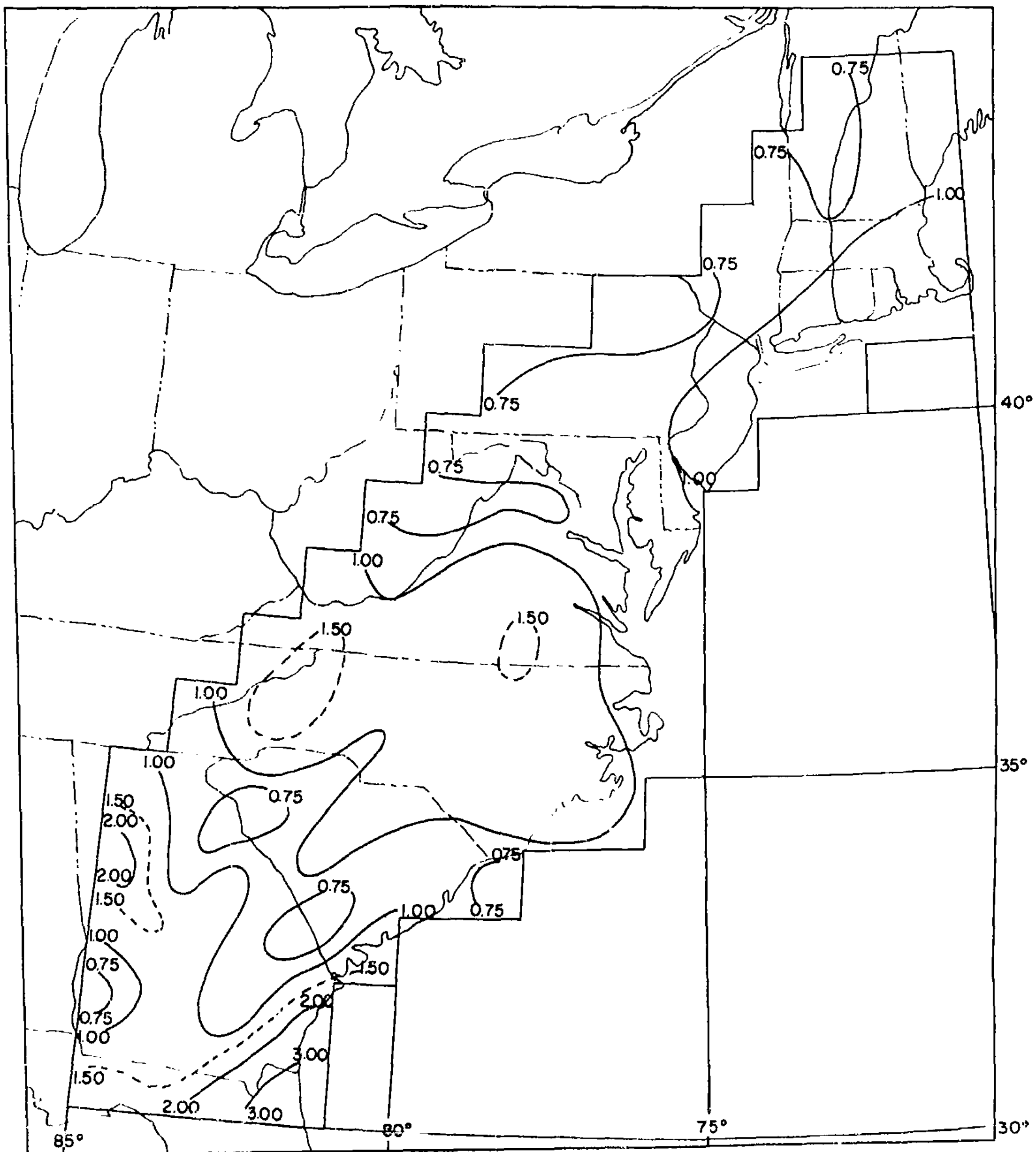

Fig. 5. Ratio of average Able to average Baker precipitation in 24-hours beginning at zero hour for region I. Based on 37 cases.

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The probability of obtaining ratios of one everywhere in random samples drawn from the same population is very nearly zero.

It would be extremely difficult to determine the statistical significance of the distribution of ratios. However, the ratios for the entire region and for the target areas have been analyzed and are discussed in the next chapter.

Composite maps were not drawn for the precipitation in region IIa (Newfoundland, Labrador and the Maritime Provinces) because of the lack of contiguity of that region.

The sea-level pressure change fields for the twenty-four hours after zero hour in the east coast region (region I) are shown for the Able and Baker samples in figures 6 and 7 respectively. These composite maps, which are drawn for all thirty-seven cases, should be compared with those for experiment ONE (Figs. 15 and 16 in No. 1). In ONE, both Able and Baker composites showed katallobaric centers in about the same position (southeast of Cape Cod) with maxima of -12.0 mb for the Able and -13.4 mb for the Baker group. The combined data also give about the same positions for the katallobaric centers but the magnitudes of the maximum pressure falls are now -8.8 mb for the Able and -12.5 mb for the Baker group. In this case increasing the sample size increased the disparity between the two groups of cases.

The difference between the combined Able and Baker charts is due largely to the contribution of experiment TWO. The composite analysis of TWO shows a maximum mean pressure change in region I of -7.2 mb for the Able cases and -11.3 mb for the Baker cases. Thus in both years the composite maps show greater pressure falls in the unseeded sample. However, in the second year, when the seeding rate was greater, the difference between the seeded and unseeded samples was larger than in the first.

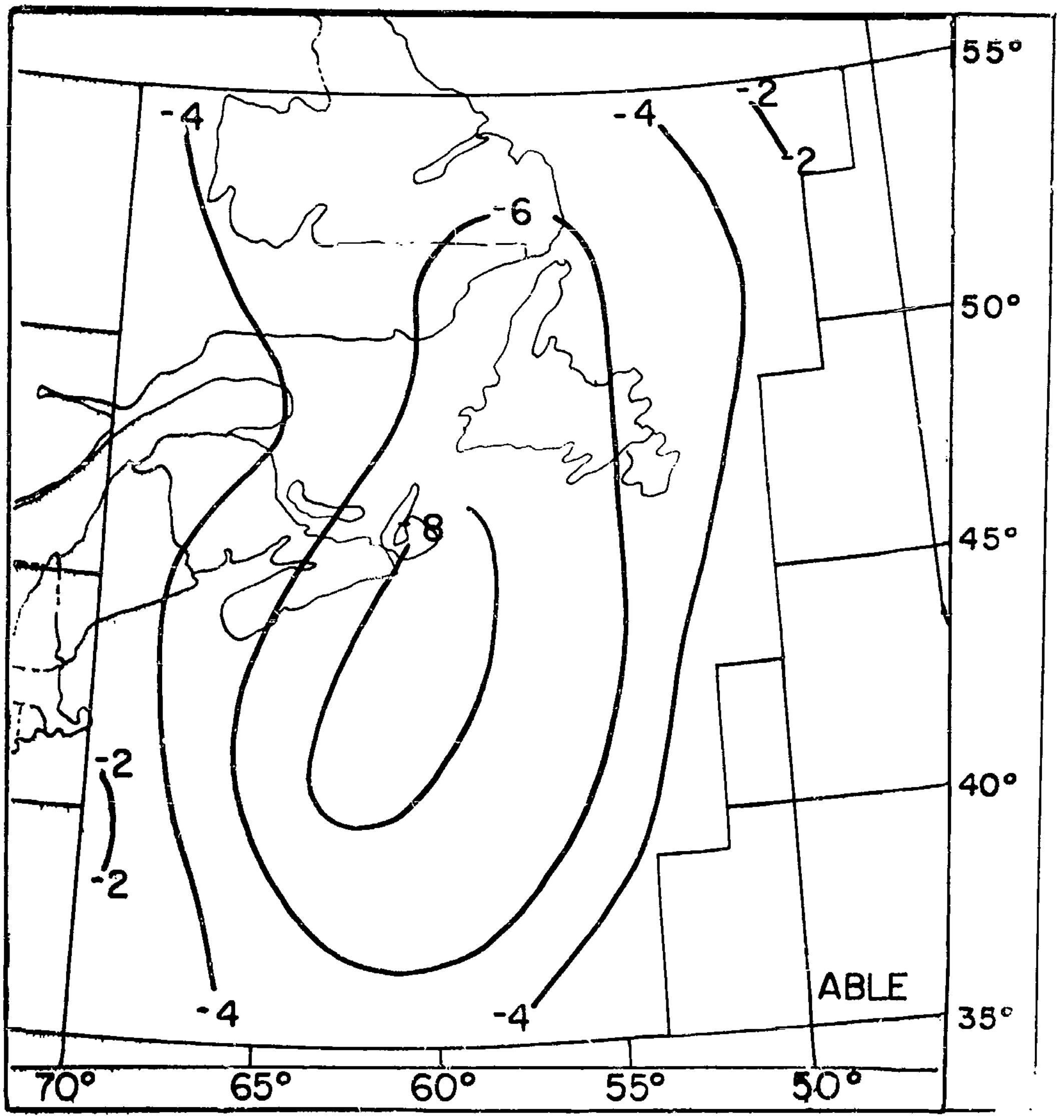

Fig. 6: Average 24-hour sea level pressure change (mb) beginning at zero hour, for 19 Able cases. Region I.

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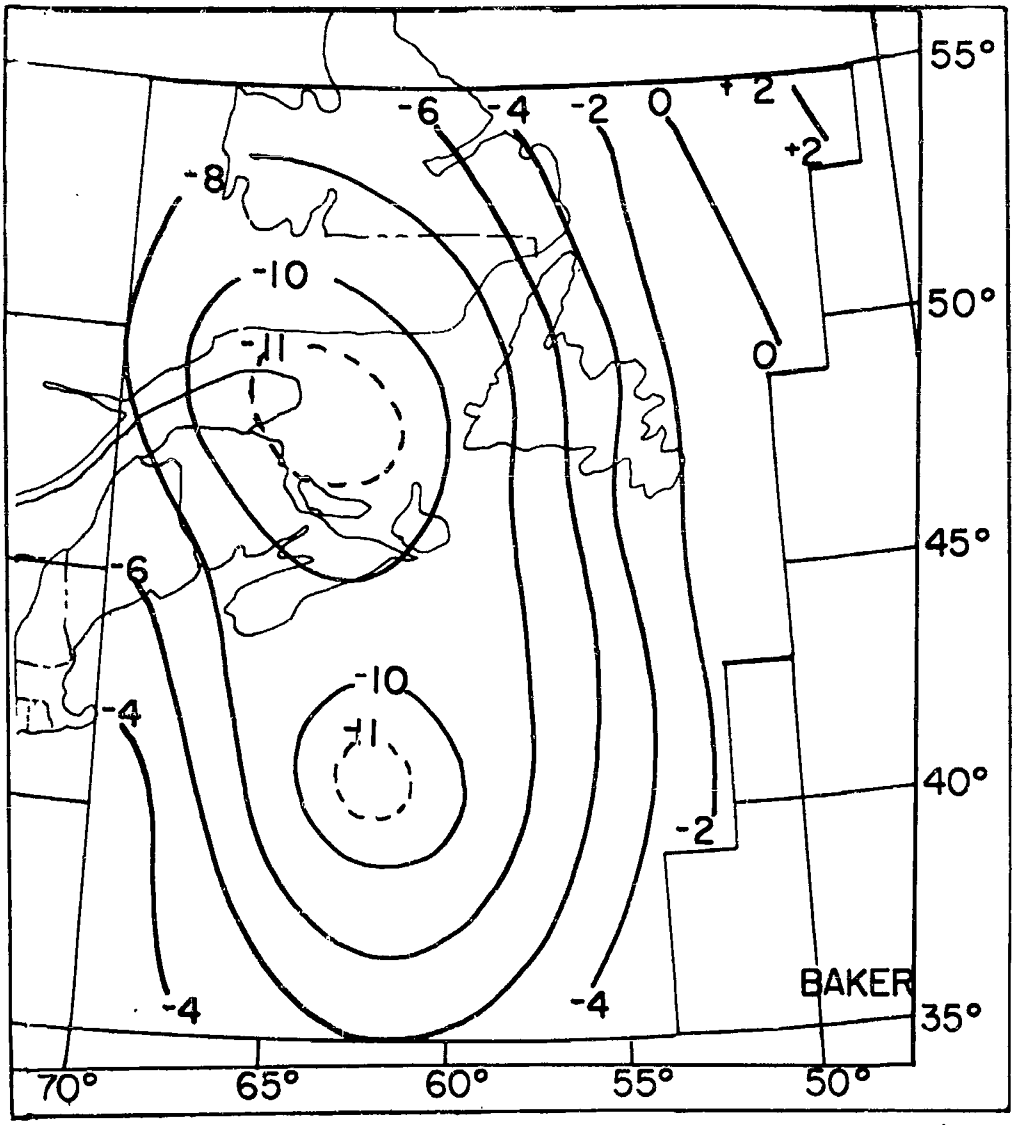

Fig 7: Average 24-hour sea level pressure change (mb) beginning at zero hour, for 18 Baker cases. Region I.

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The distribution of the differences between Able and Baker mean pressure changes in region I is shown in figure 8. The question as to whether or not these differences can be attributed to seeding is discussed in the chapter on the statistical analysis.

As might be expected, the trend of the pressure changes in the region of the Maritime Provinces (region II) is similar to that in region I. In experiment ONE the 24-hour sea level pressure change in region II in the period beginning 12 hours after zero hour showed (see figures 17 and 18 in No. 1) two katallobaric centers in the Able and Baker cases. The primary maxima were -13.7 and -11.4 mb in the Able and Baker groups respectively and were located south of Nova Scotia. The composite maps for ONE-plus-TWO (figures 9 and 10) show only a single center in the Able cases (-8.6 mb) near Sable Island while the Baker cases show again two centers, one near the Gaspé Peninsula (--11.4 mb) and another south of Nova Scotia (-11.0 mb). As in region I, the composite maps for the combined data indicate the occurrence of larger pressure falls in the Baker than in the Able group. This result is again due to the contribution of experiment TWO, since in ONE the seeded cases experienced the greater pressure fall. The composite analysis of TWO gives a maximum mean pressure change of -6.1 mb in the seeded cases and -11.9 mb in the unseeded cases.

The distribution of the differences between Able and Baker mean pressure changes in region II is shown in figure 11. The statistical significance of the differences is discussed in the next chapter.

It is probably safe to make the subjective judgment that, compared with the variance of the data, the differences between the composite maps for the seeded and unseeded samples are not large enough to warrant the conclusion that the seeding produced large scale atmospheric changes.

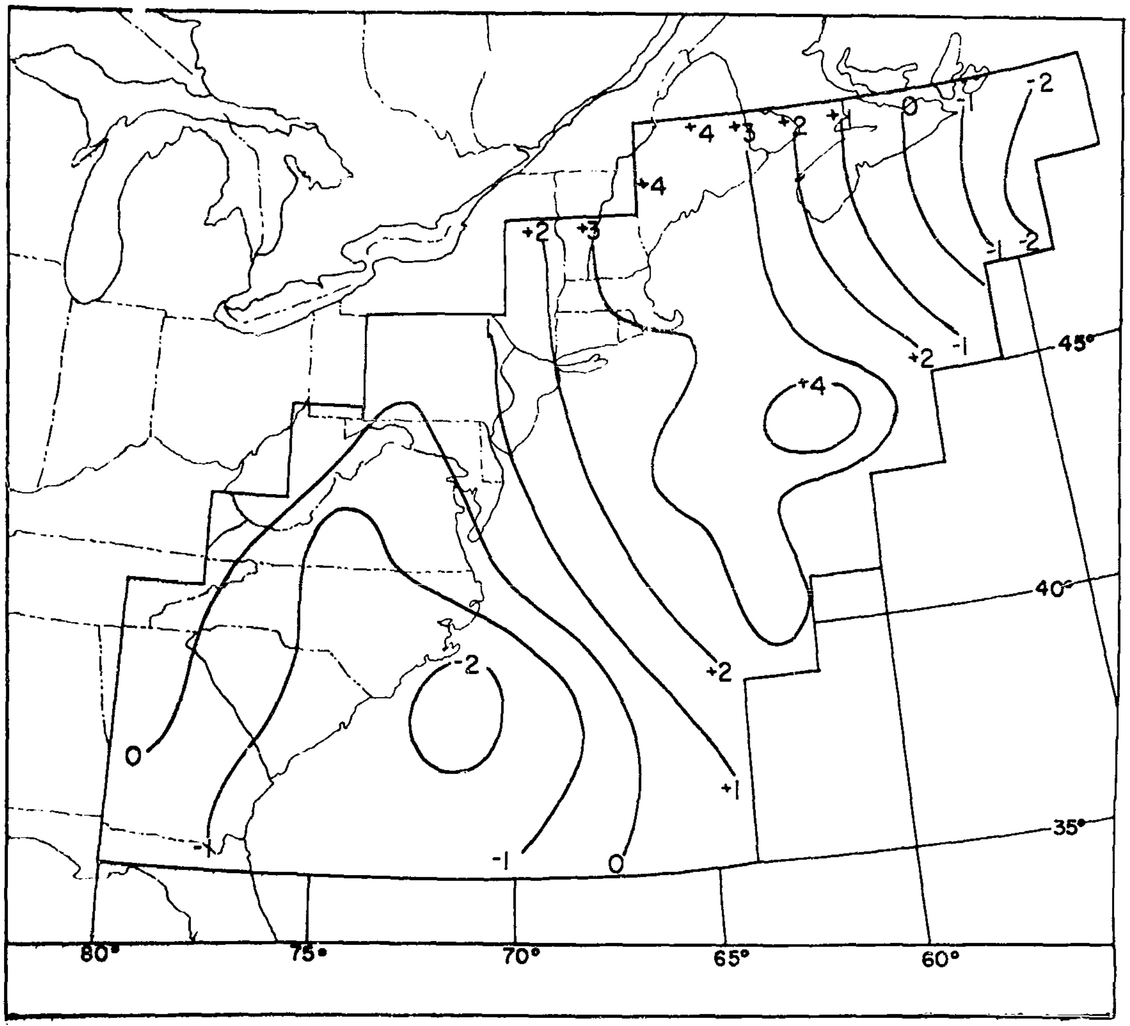

Fig. 8. Difference (mb) between average Able and average Baker 24-hour sea level pressure change (mb) (A-B) beginning at zero hour. Region I.

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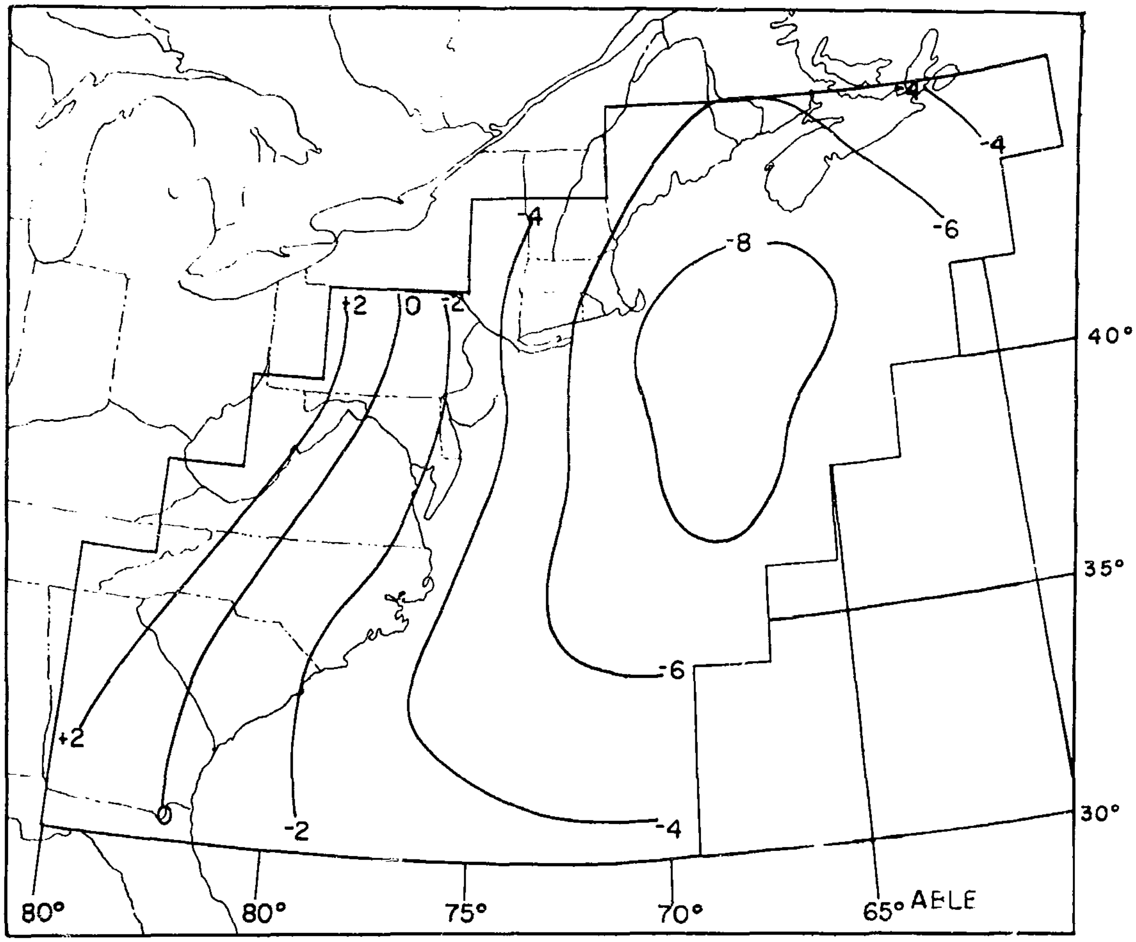

Fig. 9. Average 24-hour sea level pressure change (mb) beginning at zero - plus -12 hours, for 19 Able cases. Region II.

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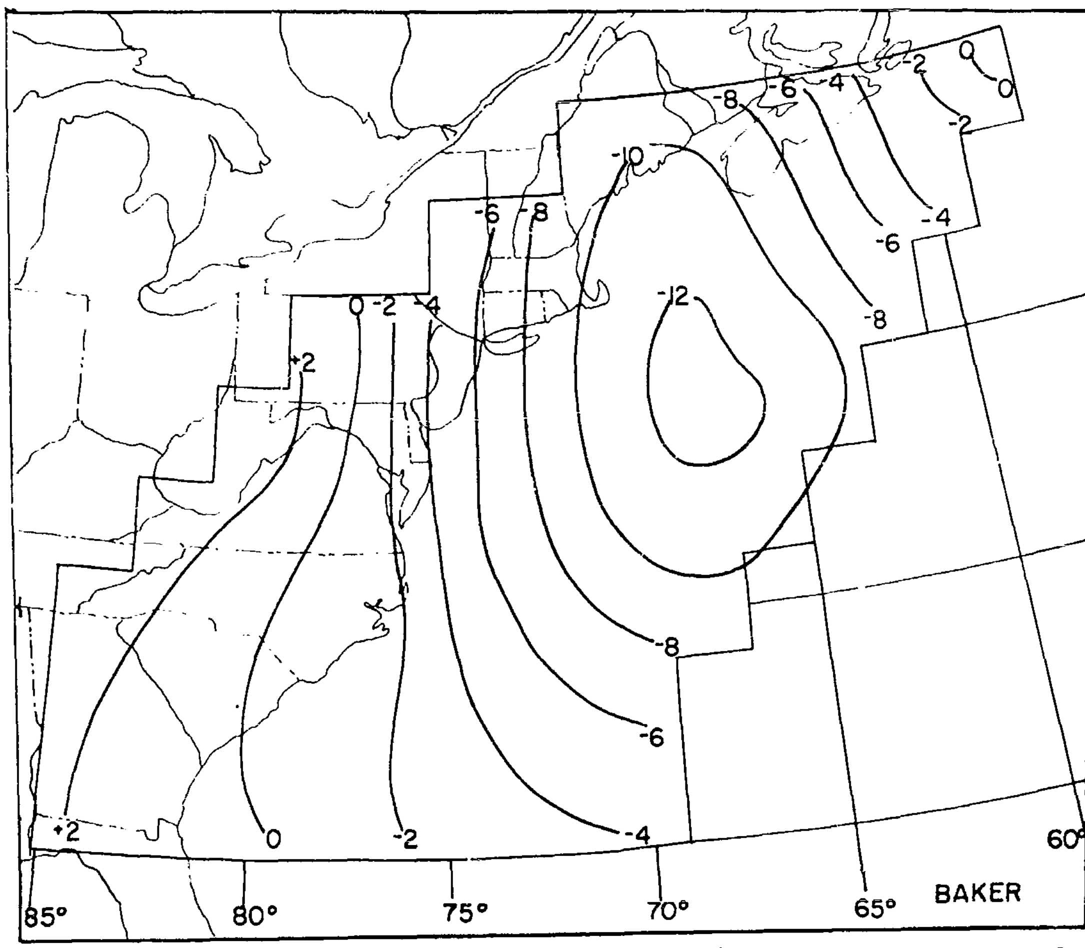

Fig 10: Average 24-hour sea level pressure change (mb) beginning at zero-plus-12 hours, for 18 Baker cases. Region II.

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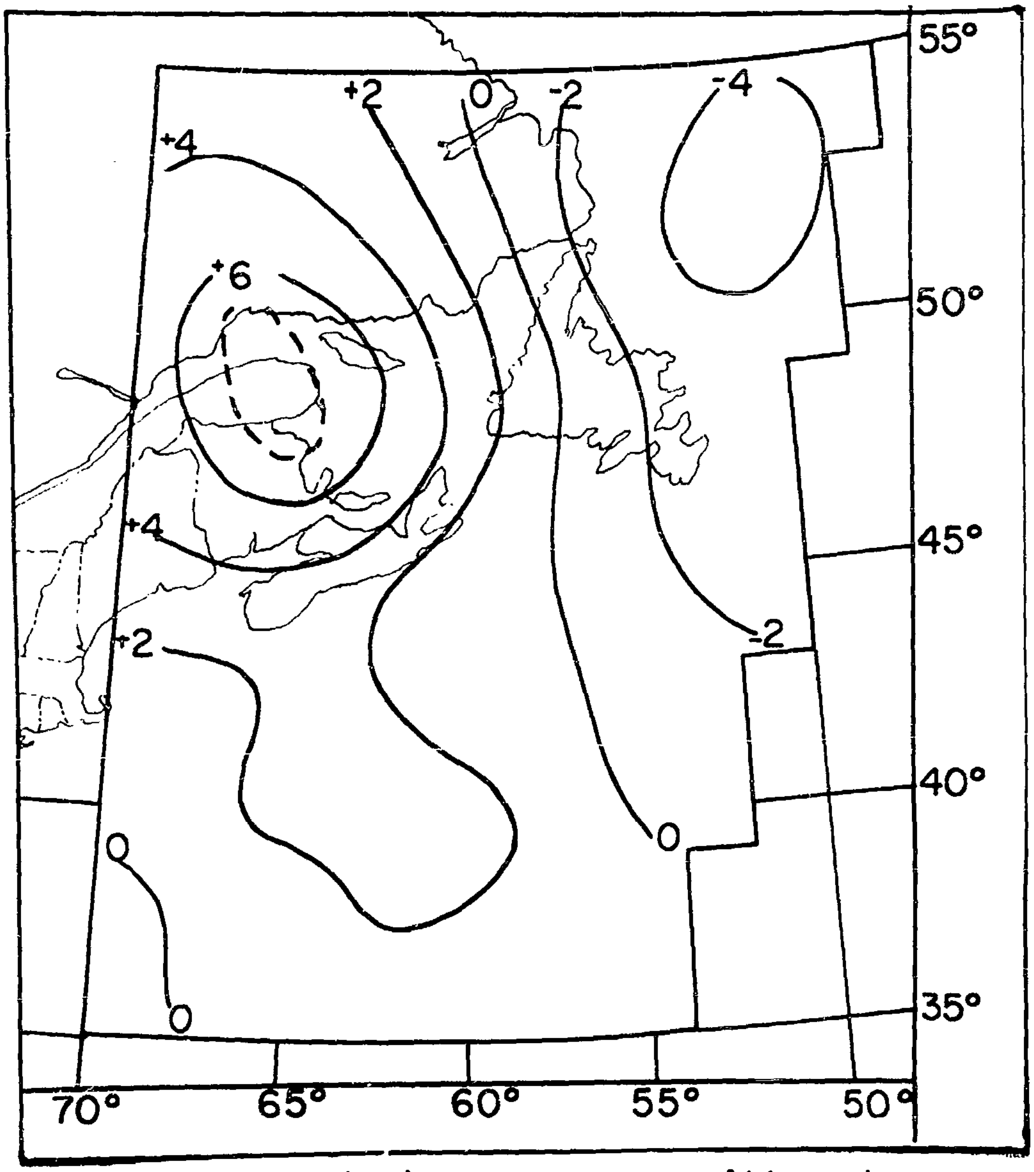

Fig. 11. Difference (mb) between average Able and average Baker 24-hour sea level pressure change (A - B) beginning at 12 hrs. after zero hour. Region II.

It may be argued that the requirements of statistical proof are too stringent and that the statistical method may lead to an justif■ied rejection of the hypothesis that seeding has an effect upon the weather. For example, it is not impossible that, in one or more of the seeding experiments conducted by Project SCUD, the weather was affected by the seeding, although the statistical analysis might not reveal this effect because of the dilution of effective seeding with ineffective seeding or because of a poor choice of test variates.

In certain seeding experiments, notably those designed to investigate the effect of seeding on supercooled stratus clouds, the treatment effect is often so obvious (e.g., the cutting of furrows and holes) that no statistical inquiry is necessary and the hypothesis is adequately proven by visual observations and photography. It is more difficult to demonstrate by the direct method that seeding does or does not produce large scale weather modification since the meteorological data which must be used permit greater latitude in interpretation. It is, in general, impossible to determine whether a single meteorological event would have occurred even if no seeding had been done. It is for this reason that we have adopted, for this project, the statistical method as our basic method of investigation.

Although visual observations and synoptic analysis cannot be used in this experiment to prove the case for or against seeding, they may provide useful clues and suggestions that may be pursued later by the less subjective statistical methods. For this reason special attention was devoted to those seeding trials in which either the character of the seeding was such as to warrant the expectation of an effect or some cloud modification was observed to follow the seeding with dry ice.

In case No. 22 on 4 December 1953, the assigned target area was No. 4. Due to mechanical trouble the red and blue flights did not reach the assigned area. Instead red flight dispensed 2475 lbs of dry ice into area 3 between New Bern, N.C. (at 1825 Z) and Georgetown, S.C. (at 1935 Z) while blue flight dispensed 2475 lbs of dry ice in area 1 between Savannah, Ga. (at 1730 Z) and Brunswick,Ga. (at 1810 Z). Both planes were in clouds during the seeding operation at temperatures between -5 and -10° C. (The reason given for the abortion of red flight was failure of the starboard wing de-icer and the accumulation of moderate rime ice at 18,000 feet over New Bern.) Red flight seeded at the rate of 13 lbs per mile while blue flight seeded at the rate of 35 lbs per mile.

Green flight in case No. 22 took over the blue track in target area 4 and dispensed 2475 lbs between New Bern, N.C. (at 1835 Z) and Greensboro, N.C. (at 1939 Z). The seeding rate on this flight was 14 lbs per mile. The plane was either in the clouds or between layers at 20,000 feet during the flight.

This case was singled out for special consideration because of the high seeding rates employed, the large amount of dry ice dispensed, and the existence of an almost ideal seeding situation (solid, thick cloud layers and icing conditions).

The surface weather map (see Fig. 14 in Appendix) for zero hour (1830 Z) showed a cold front extending from Michigan through Alabama and moving slowly eastward. A squall line oriented north-south was entering target area 4 and was just passing off the coast of Georgia. Rain and thunderstorms were occurring generally over Virginia, the Carolinas, southeastern Georgia and northern Florida.

The rainfall distribution before seeding is shown in figure 12 (a). In the six hours before zero hour (1230 Z - 1830 Z, 4 December 1953), the rainfall was particularly heavy over the Carolinas, Georgia and Florida with six-hour amounts

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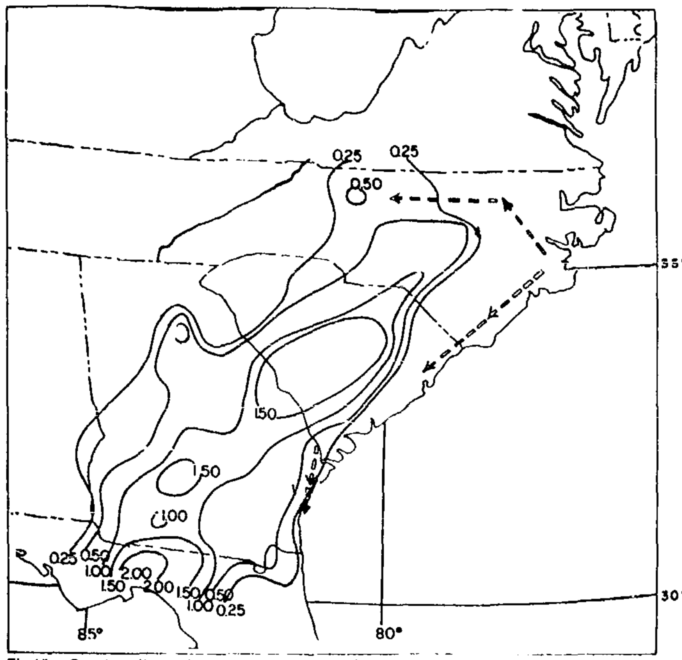

Fig.12a. Rainfall (inches) between 1230 and 1830 GMT, 4 December 1953.

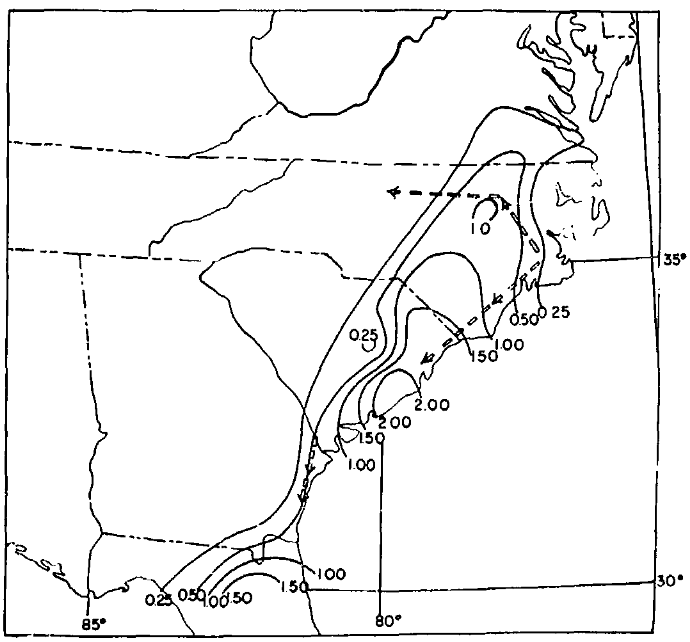

Fig. 12 b. Rainfall (inches) between 1830 GMT 4 December and 0030 GMT 5 December 1953

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ranging from 1 to 2 inches on a line running from Tallahassee to Fort Bragg. (Tallahassee reported 2.04 inches in six hours.)

Figure 12 (B) shows the rainfall in the six-hour period following zero hour. The line of heaviest precipitation now runs from Jacksonville to Rocky Mount with amounts ranging from 1 to 2 inches. (Charleston, S.C. reported 2.18 inches in this six-hour period.) There was little change in the shape of the precipitation field and the six-hourly amounts remained about the same. The precipitation field appears to have moved eastward with the squall line at a speed of about 17 miles per hour.

If the seeding had an effect on the rainfall, it is not obvious from the rainfall distributions of figure 12.

There were only two occasions on which visible cloud modification was reported. These occurred on 11 February and 26 February 1954. It is quite possible that the clouds were modified at other times. However, many of the flights were conducted in clouds. In these cases no observations of cloud modification were possible. Furthermore, the planes may not have remained in the seeded area long enough to witness an effect.

On February 11, 1954 (see Figs. 30-33) the red, blue and green flights began dispensing dry ice over target area 4 at 1850 Z, 1850 Z and 1908 Z respectively. Blue flight seeded between Rocky Mount and Greensboro during the period 1850 Z - 1945 Z. At this time there was a solid undercast below 18,000 feet with clouds built up in places above 20,000 feet. This track was retraced by red flight between 2048 Z and 2115 Z. At that time, about two hours after it had been seeded, this track was almost void of clouds. Red flight reported that there existed an almost clear path eight to ten miles wide between Greensboro and Rocky Mount with a bank of altostratus to the north and towering cumulus to the south.

At 2013 Z green flight was seeding into broken altocumulus and altostratus (see cross-section, Fig. 33 in Appendix) near Lynchburg at 19,000 feet (temperature -20° C) when a trail of large, swelling, cumulus type clouds was observed building up out of the altostratus. The trail started about a quarter of a mile (five seconds) behind the aircraft. The new clouds appeared to be about a quarter of a mile wide and one to three thousand feet above the top of the altostratus deck immediately behind the airplane. About ten miles behind the airplane "the trail appeared to be about three miles wide and five to six thousand feet high". "The buildups in the trail had a noticeable 'boiling' appearance and grew quite rapidly in size". At 2033 Z over Pulaski the green flight observer was able to see (and photograph) a similar trail of buildups behind the red aircraft which was seeding at the time. The ridge of cloud resulting from the seeding is shown in figure 13. This photograph was made near Pulaski, Va. at 2037 Z with 35 mm Kodachrome film. The diagonal shadow in the lower part of the picture marks the vertical wall of the cloud ridge. In the upper part of the picture can be seen the cloud ridge resulting from red flight's seeding. The cumulus trail behind green flight persisted during the entire seeding operation from Lynchburg (2003 Z) to near Quantico (2123 Z).

It is not possible to state with any degree of certainty that the cloud dissipation observed between Greensboro and Rocky Mount was caused by seeding. The hourly observations from airways stations in North Carolina indicate that the clouds were stratified and variable during this period with some indications of natural dissipation. The winds aloft were beginning to veer to the west at the same time which would also indicate cloud dissipation. On the other hand,

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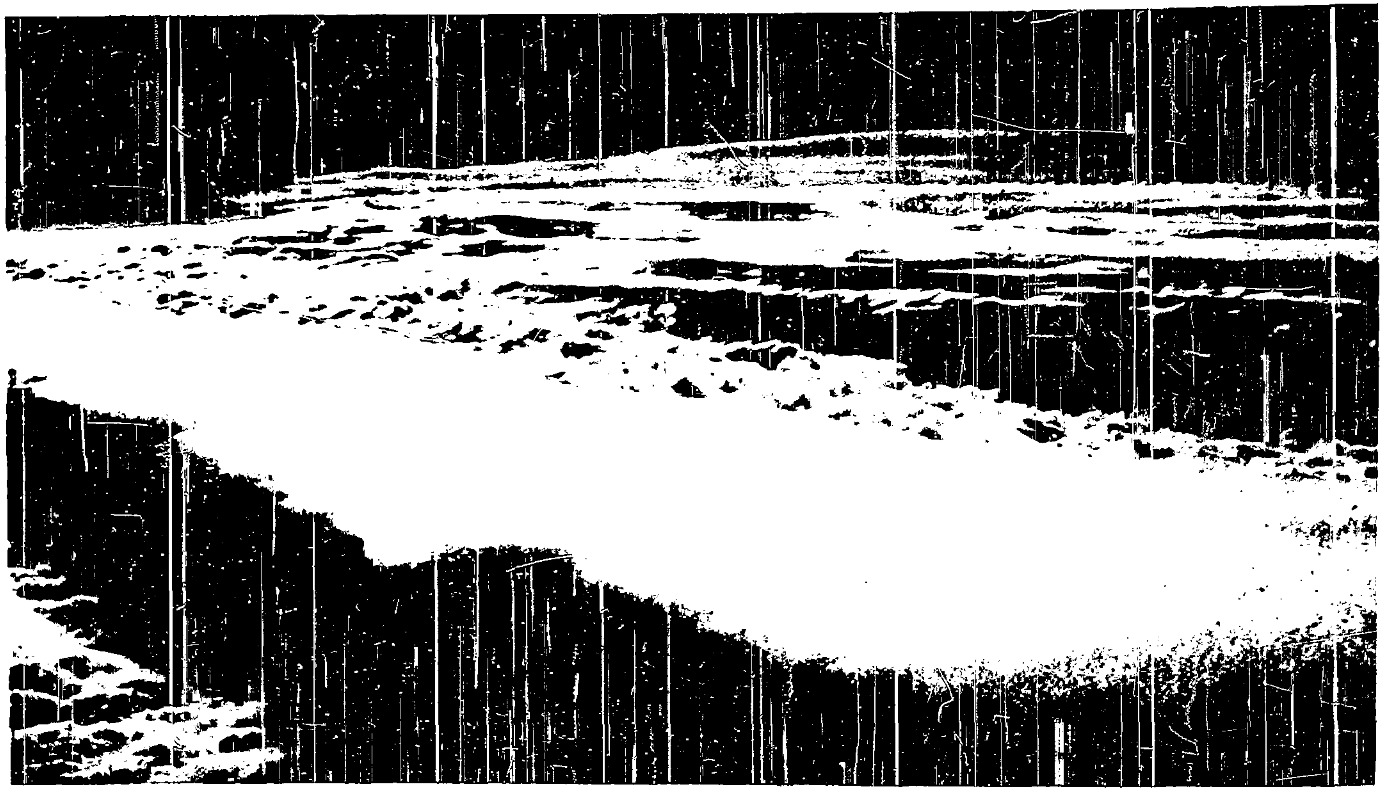

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Fig 13: Cloud line development following seeding with dry ice. Time 2037 GMT. Date: 11 Feburary 1954. Elevation: 19000 feet. Location: Pulaski, Va.

the reports by red and blue flights of generally good seeding conditions everywhere except on this one leg does argue in favor of artificial dissipation. This case only serves to illustrate the impossibility of deducing anything from a single meteorological event.

The report of cumulus-like cloud development following the airplane is the kind of direct evidence of cloud modification that can hardly be disputed. It is of some interest to determine if the seeding, which caused the cloud modification, could also have caused precipitation to fall in this region.

The cumulus buildups were reported beginning at 2003 Z over Lynchburg, 2033 Z over Pulaski, 2045 Z over Roanoke, 2054 Z over Lynchburg, 2107 Z over Gordonsville and 2116 Z over Quantico. The hourly reports for these stations show the following weather sequences:

Lynchburg:	1930 Z, scattered clouds
	2030 Z, overcast (7,500 feet)
	2130 Z, very light rain
Pulaski:	1930 Z, very light rain began 1925 Z
	2030 Z, broken clouds (10,000 feet)
	2130 Z, clear
Roanoke:	1930 Z, overcast (14,000 feet)
	2030 Z, broken clouds (5,500 feet)
	2130 Z, scattered clouds
Gordonsville:	1930 Z, overcast (20,000 feet)
	2030 Z, overcast (20,000 feet)
	2130 Z, broken clouds (15,000 feet)
Quantico:	1930 Z, overcast (20,000 feet)
	2030 Z, overcast (20,000 feet)
	2130 Z, broken (20,000 feet)

It appears that, with the exception of Lynchburg, there was a tendency in the seeded area for cloud dissipation.

It should also be noted that none of the 29 weather stations in our Virginia network reported any measurable precipitation between 1230 Z 11 February and 1830 Z 12 February 1954.

If anything can be concluded from this one case, it is that the conditions which may be favorable for the artificial modification of clouds are not necessarily favorable for the artificial stimulation of measurable precipitation.

The only other report of apparent cloud modification occurred on 26 February 1954. While seeding in area 6 between Poughkeepsie and Worcester, green flight reported that "the tops of the cumulus layers appeared to have a thin, wispy, vertical development in the seeded area. During the passage through a thin layer of stratus clouds the seeding had an effect of first cutting a furrow through the layer then showing slight vertical development". Seeding was conducted between 1427 Z and 1511 Z in this region at an altitude of 19,000 feet in and out of cloud tops.

At Poughkeepsie very light rain began at 1422 Z (five minutes before seeding began over the station) and ended at 1447 Z. Albany reported no measurable precipitation between 0630 Z and 1830 Z nor did Pittsfield, Birch Hill Dam and Knightsville Dam, Mass., all of which were on the seeded track. Of course, the effect of the seeding may have been too localized to have been experienced by the weather stations. But certainly there is no evidence of an increase in precipitation as a result of the seeding.

Chapter IV. Statistical Analysis

In testing for the effect of a treatment (e.g. cloud seeding) the obvious procedure, after the experimental units, the treatment, and the test variates have been defined, is to divide the test units into two samples, one of which is treated and the other of which is not. We then compare the properties of the two samples. A convenient property for comparison is the sample mean of a test variate which has been agreed on in advance of the experiment.

There are certain precautions which must be taken in the experiment to minimize bias. Randomization of the treatments is one. Specification of the test variates (in terms of which the experimental hypothesis is stated) in advance of the experiment is another.

It is obvious that mere inspection of the two sample mean values does not necessarily give the desired information. First of all the differences between the means may be accounted for (at least partially) by non-treatment differences between the samples. It is true that in a randomized design these non-treatment differences generally diminish as the sample size increases. But in this experiment we have to deal with small samples. If we have some basis for making even crude estimates of the test variates from certain predictors (covariates), we can adjust the individual values, and hence the sample means, for variations in the covariates. (The method of adjustment and the general method of analysis of covariance are described in text books on statistics. See, e.g. G. W. Snedecor, Statistical Methods. Iowa State College Press, 1946.)

After the sample means have been adjusted, it is still necessary to take into account the variability of the individual values which enter into the means. From the variability it is then possible to determine confidence limits for the difference of the "true" means of the two samples (see, e.g. Snedecor). Obviously a given difference between two sample means contains more information if the variability is small than if it is large.

The results of the analysis of covariance as applied to the several test variates of the experiment are described below.

A. $\underline{R_1}$. The average rainfall in the east-coastal region (region Ia) in the twenty-four hours beginning at zero hour was selected prior to experiment ONE as one of the basic test variates for the experiment. It was stipulated at that time that R_1 would be adjusted for the index, M, and block effects would be removed (see No. 1). Later, after the termination of ONE, two additional covariates, T and L (see Chapter I) were introduced and it was agreed that these should not be used on the ONE data except as an admitted afterthought.

All of the statistical analysis of precipitation was applied to logarithms of the precipitation on the assumption that the treatment effect should be proportional to the precipitation itself. The use of logarithms indicates that geometric rather than arithmetic means of the Able and Baker samples are compared in the analysis.

The observed and adjusted means for R_1 as well as confidence limits are given in table 3. All adjustments and confidence limits refer to the geometric means. Note that the arithmetic means are calculated for all cases, whereas the geometric means and adjusted means are calculated by omitting the unpaired case number 21.

Table 3. Means and confidence limits for R_1 (inches)

	Experiment	Able	Baker	No. of Cases
Observed Arithmetic Mean	ONE	0.336	0.301	21
Observed Geometric Mean	ONE	0.250	0.220	20
Adjusted Mean (for M)	ONE	0.221	0.250	20
95% confidence limits for ratio of means	ONE	$0.44 < \frac{A}{B} < 1.80$		20
Observed Arithmetic Mean	TWO	0.305	0.309	16
Observed Geometric Mean	TWO	0.196	0.240	16
Adjusted Mean (for (M,T,L)	TWO	0.201	0.234	16
95% confidence limits (M,T,L) for ratio of means	TWO	$0.51 < \frac{A}{B} < 1.87$		16
Observed Arithmetic Mean	ONE + TWO	0.322	0.305	37
Observed Geometric Mean	ONE + TWO	0.224	0.229	36
Adjusted Mean (for M)	ONE + TWO	0.212	0.243	36
95% confidence limits (M) for ratio of means	ONE + TWO	$0.57 < \frac{A}{B} < 1.34$		36
Adjusted Mean (for M,T)	ONE + TWO	0.201	0.256	36
95% confidence limits (M,T) for ratio of means	ONE + TWO	$0.53 < \frac{A}{B} < 1.16$		36
Adjusted Mean (for M,T,L)	ONE + TWO	0.220	0.233	36
95% confidence limits (M,T,L) for ratio of means	ONE + TWO	$0.66 < \frac{A}{B} < 1.35$		36

The symbols A and B in the confidence statements represent the "true" adjusted means of seeded and unseeded cases.

The most striking feature of table 3 is the small difference between the Able and Baker means. For the 37 cases the difference of arithmetic means (unadjusted) is about 5% of the mean. The difference of the unadjusted geometric means is about 2% of the mean.

After adjustment for the circulation index, the ratio of Able to Baker geometric means is 87% indicating the possibility of a negative effect of seeding on large scale precipitation. The variance of the data is such, however, that the 95% confidence limits enclose an interval between a reduction by seeding of 43% and an increase by seeding of 34% ($0.57 < A/B < 1.34$). We may say, with only about one chance in twenty of being wrong, that seeding did not increase the large scale precipitation, R_1, more than 34% nor decrease R_1 more than 43%.

The last two confidence limits in table 3 were computed as afterthoughts by adjusting both the ONE and TWO data for the covariates M, T and L. Although it is not immediately obvious from the antilogarithms, the addition of each covariate has the effect of narrowing the confidence interval on the logarithms. While the last confidence interval (with adjustments for M, T and L) was admittedly constructed as an afterthought, it is probably our best estimate of the confidence interval. It appears that the most we can say with respect to R_1 at this time is that (a) after adjustments have been made for covariates, the observed mean precipitation is slightly greater in the unseeded than in the seeded sample and (b) there is only about one chance in twenty that seeding either increased the R_1 precipitation more than 35% or decreased it more than 34%.

B. $\underline{R_2}$. The average rainfall in the Maritime Provinces (region IIa) in the twenty-four hours beginning at zero-plus-twelve hours was also one of the primary test variates in experiment ONE. R_2 was selected to represent the delayed effect of seeding (on large scale precipitation) downwind of the seeded area.

The observed and adjusted means and confidence limits for R_2 (based on the analysis of logarithms) are given in table 4.

Table 4. Means and confidence limits for R_2 (inches)

	Experiment	Able	Baker	No. of Cases
Observed Arithmetic Mean	ONE	0.212	0.172	21
Observed Geometric Mean	ONE	0.085	0.079	20
Adjusted mean (for M)	ONE	0.068	0.098	20
95% condifence limits for ratio of means	ONE	$0.28 < \frac{A}{B} < 1.71$		20
Observed Arithmetic Mean	TWO	0.146	0.233	16
Observed Geometric Mean	TWO	0.085	0.148	16
Adjusted mean (for M,T,L)	TWO	0.087	0.145	16
95% confidence limits for ratio of means	TWO	$0.28 < \frac{A}{B} < 1.12$		16
Observed Arithmetic Mean	ONE + TWO	0.184	0.174	37
Observed Geometric Mean	ONE + TWO	0.088	0.107	36
Adjusted mean (for M)	ONE + TWO	0.083	0.112	36
95% confidence limits for ratio of means	ONE + TWO	$0.36 < \frac{A}{B} < 1.50$		36
Adjusted mean (for M,T,L)	ONE + TWO	0.079	0.118	36
95% confidence limits for ratio of (M,T,L) means	ONE + TWO	$0.32 < A < 1.39$		36

It is interesting to note that the rather large difference between arithmetic means of R_2 which we observed in ONE was reversed in TWO. Thus when the data for ONE and TWO are combined, the difference between the arithmetic means of R_2 is only about six percent of the mean. However, the difference between unadjusted geometric means is about twenty percent of the mean with greater precipitation in the unseeded cases.

The 95% confidence limits for TWO are rather surprising in that, with only eight pairs of cases, they permit the statement that the probability is 95% that seeding did not increase rainfall more than 12% (nor decrease it more than 72%) in this region.

This skewness of the confidence interval suggests the possibility that further experiments might reveal a negative effect of seeding on rainfall downwind of the seeded area.

The combined data give 95% confidence limits representing an increase of 50% and a decrease of 64% if adjustments are made only for M. When adjustments are made for the three covariates, M, T and L, the 95% confidence interval lies between an increase of 39% and a decrease of 68%.

Of course, since the confidence interval straddles unity (representing no difference between seeded and unseeded samples) the result is again not significant at the 95% level.

C. P_1. The average 24-hour sea level pressure change in the east coastal region was selected at the beginning of experiment ONE as a measure of the effect of seeding on cyclone development.

The only covariate used in the analysis of P_1 was the zero hour circulation index, M. Some thought was given to the possibility of using some form of prognosis of the pressure field as a covariate. However, no objectively determined prognosis was available for the experimental cases. It is doubtful that prognostic maps would have contributed appreciably to improving the precision of the experiment anyway since the situations selected for the experiment are precisely those for which present forecasting techniques are least successful.

Means and confidence limits for P_1 are given in table 5.

Table 5. Means and confidence limits for P_1 (millibars)

	Experiment	Able	Baker	No. of cases
Observed mean	ONE	-6.35	-4.74	21
Adjusted mean	ONE	-5.96	-5.30	20
95% confidence limits	ONE	$-6.34 < (A-B) < 5.22$		20
Observed mean	TWO	-1.03	-5.03	16
Adjusted mean	TWO	-0.76	-5.30	16
95% confidence limits	TWO	$-3.06 < (A-B) < 12.14$		16
Observed mean	ONE + TWO	-4.11	-4.87	37
Adjusted mean	ONE + TWO	-3.65	-5.30	36
95% confidence limits	ONE + TWO	$-2.55 < (A-B) < 5.85$		36

In experiment ONE the pressure decreased slightly more in the seeded than in the unseeded cases. However, the difference between the two pressure changes was not significant and the confidence limits for the difference of true means of the pressure changes were about plus 5 and minus 6 mb.

In TWO the mean pressure fall in the unseeded cases was much greater than in the seeded cases. The 95% confidence interval for the difference of means lay between plus 12 and minus 3 mb. This difference is not statistically significant, but the possibility is indicated that further experimentation might reveal that seeding tends to reduce cyclone intensity. (In comparing the results for ONE and TWO it must be remembered that the dry ice seeding rate was five times as great in TWO as in ONE.)

When the data for ONE and TWO are combined, the overwhelming negative contribution of TWO is still apparent. Again the pressure fell more in the unseeded cases. However, the 95% confidence interval does not exclude the possibilities of negative, positive or zero effects.

D. $\underline{P_{ml}}$. The maximum 24-hour sea level pressure fall in the east coastal region in the period beginning at zero hour was selected as a test variate prior to experiment TWO. P_{ml} was also calculated and analyzed for ONE and for ONE-plus-TWO, but this procedure is clearly an afterthought.

Largely because of variations in the distribution of the sea level pressure changes, the quantity p_1 proved to be a rather unsatisfactory variate. The co-existence of pressure rises as well as pressure falls in the east coastal region resulted in small and probably non-meaningful values for P_1. By selecting the largest pressure fall in the region, P_{ml}, regardless of its location, much of the difficulty with P_1 is eliminated. Also, P_{ml} is more closely identified with cyclone development than the large scale pressure variate, P_1. It is felt that the analysis of P_{ml}, although it was an afterthought to some extent, is more relevant to the problem of the experiment than that of P_1.

The only covariate used for P_{ml} was the circulation index, M.

Means and confidence limits for P_{ml} are shown in table 6.

Table 6. Means and Confidence limits for P_{ml} (millibars)

	Experiment	Able	Baker	No. of Cases
Observed Mean	ONE	-21.75	-19.76	21
Adjusted Mean	ONE	-22.68	-19.77	20
95% Confidence limits	ONE	$-11.74 < (A-B$	< 5.92	20
Observed Mean	TWO	-15.94	-18.76	16
Adjusted Mean	TWO	-15.97	-18.73	16
95% Confidence limits	TWO	$-3.13 < (A-B)$	< 8.67	16
Observed Mean	ONE + TWO	-19.30	-19.31	37
Adjusted Mean	ONE + TWO	-19.61	-19.31	36
95% Confidence limits	ONE + TWO	$-5.37 < (A-B)$	< 4.94	36

The observed means are interesting in themselves. In ONE the mean pressure fall was greater in the seeded cases. In TWO the mean pressure fall was greater in the unseeded cases. But when the data for both years are combined, the mean pressure change for the seeded and unseeded samples are almost identical.

(Of course, the dry ice seeding rate was greater in TWO than in ONE. It may be that the rate of one pound per mile increases the pressure fall whereas a seeding rate of five pounds per mile decreases the pressure fall. But this hypothesis cannot be proved with the experimental data collected thus far.)

Although the difference between the adjusted means of P_{ml} was only -2.91 mb in ONE, the 95% confidence interval for the difference between true means lies between -11.74 and + 5.92 mb. In TWO the difference between the adjusted means

(A - B) was only + 2.75 mb and the 95% confidence interval for the difference between true means lies between +8.67 and -3.13 mb.

The difference between adjusted means for the combined data of ONE and TWO is only -0.22 mb, about 1% of the mean value of P_{m1}. However, the variance is such that the 95% confidence limits for the difference of true means are +4.94 and -5.37 mb. Thus, there is about one chance in twenty that the seeding either increased or decreased p_{m1} more than about 5 mb.

E. $\underline{P_2}$. The average 24-hour sea level pressure change in the area northeast of the seeded region for the period beginning twelve hours after zero hour was one of the primary test variates selected at the beginning of the experiment.

P_2 like P_1 suffers from the defect that negative pressure changes in the area may be negated by positive changes in another part of the same region. The quantity is therefore only a rather gross and insensitive measure of cyclone development.

The means and confidence limits for P_2 are shown in table 7.

The covariates used for the analysis of P_2 were the circulation index, M, and P_1.

Table 7. Means and Confidence limits for P_2 (millibars)

	Experiment	Able		Baker	No. of Cases
Observed mean	ONE	-8.08		-5.57	21
Adjusted mean	ONE	-8.19		-5.99	20
95% Confidence limits	ONE	-10.06	$<$ (A - B) $<$	5.64	20

Table 7 Means and Confidence limits for P_2 (millibars)

	Experiment	Able		Baker	No. of Cases
Observed mean	TWO	-1.19		-7.15	16
Adjusted mean	TWO	-2.97		-5.36	16
95% Confidence limits	TWO	$-1.78 <$	$(A - B)$	< 6.56	16
Observed mean	ONE + TWO	-5.18		-6.27	37
Adjusted mean	ONE + TWO	-5.87		-5.71	36
95% Confidence limits	ONE + TWO	$-5.21 <$	$(A - B)$	< 4.89	36

The results for P_2 are rather similar to those for P_1, as might be expected. In experiment ONE the mean pressure fall was greater in the seeded cases while in experiment TWO the pressure fell more in the unseeded cases. In neither year was the difference between the mean pressure change statistically significant.

Combining the data for both years yielded the result, as in the cases of P_1, that the pressure fell only slightly more in the unseeded than in the seeded cases. However, this difference was almost entirely eliminated by the adjustment for co-variates and the difference between the two samples is not significant.

The net result for P_2, as indicated by the confidence limits, is that there is only about one chance in twenty that the difference between the true means of the average pressure change in the seeded and unseeded cases in this region was greater than about 5 mb. In view of the fact that the mean value of P_2 itself is only about 5 mb, this result is not very informative. (This same statement applies to P_1.)

F. P_{m2}. Like P_{m1}, P_{m2} was introduced after the first experiment because P_2 was obviously not very satisfactory as a measure of cyclone development. We have calculated P_{m2} for both experiments ONE and TWO although admittedly it was an afterthought as far as ONE is concerned.

The covariates used for P_{m2} were M and P_{m1}.

Means and confidence limits for P_{m2} are given in table 8.

Table 8. Means and Confidence limits for P_{m2} (millibars).

	Experiment	Able	Baker	No. of cases
Observed mean	ONE	-26.50	-22.09	21
Adjusted mean	ONE	-26.60	-23.19	20
95% Confidence limits	ONE	$-9.52 < (A - B) < 2.72$		20
Observed mean	TWO	-18.15	-22.96	16
Adjusted mean	TWO	-19.01	-22.10	16
95% Confidence limits	TWO	$-3.09 < (A - B) < 9.27$		16
Observed mean	ONE + TWO	-22.98	-22.48	37
Adjusted mean	ONE + TWO	-23.33	-22.60	36
95% Confidence limits	ONE + TWO	$-4.80 < (A - B) < 3.34$		36

The behavior of the observed means is quite similar to that of P_{m1} (table 6). In experiment ONE the mean pressure fall was greater in the seeded cases. In experiment TWO the mean pressure fall was greater in the unseeded cases. When the two years of data are combined, the difference between the two mean pressure changes is found to be only one-half millibar, a little more than two percent of the mean value of P_{m2}.

From the confidence limits on the difference between the means of P_{m2} for the combined data of ONE and TWO, we conclude that there is only about one chance in twenty that the difference between the true means of P_{m2} for the seeded and unseeded samples lies outside the interval bounded by +3.34 and -4.80 mb.

Again, as in the case of P_1 and P_{m1}, the length of the confidence interval is about the same for both P_2 and P_{m2} although the mean value of P_{m2} is about four times as large as the mean value of P_2 (just as the mean P_{m1} is about four times as large as the mean P_1.) Clearly P_{m1} and P_{m2} are far more sensitive for the purpose of this experiment than are P_1 and P_2.

G. Target area precipitation. All of the foregoing variates are large scale quantities which were designed to test the (null) hypothesis that cloud seeding does not produce large scale weather modification.

The design of experiment ONE was such that it did not permit any convenient analysis for smaller scale effects. However, in experiment TWO target areas were employed so that it was at least possible to look for effects on the scale of the target area.

Average target area precipitation in the 24-hour period beginning at zero hour (R_t) was selected prior to TWO as a new test variate. The covariates selected for the analysis of R_t were the index, M, and the partial water vapor flux T_t (see Chapter I.) Logarithms were used in the analysis of R_t.

The means and confidence limits for R_t are given in table 9 for the 16 cases of experiment TWO.

Table 9. Means and Confidence limits for target area precipitation, R_t. (inches)

Experiment TWO only

	Able	Baker
Observed Arithmetic Mean	0.414	0.365
Observed Geometric Mean	0.217	0.278
Adjusted Geometric Mean	0.225	0.268
95% Confidence limits on ratio of means	$0.20 < \frac{A}{B} < 3.52$	

Table 9 illustrates one effect of employing logarithms in the analysis of the precipitation data. Whereas the arithmetic mean of R_t is greater in the seeded cases, the geometric mean is greater in the unseeded cases. The reason for this discrepancy lies in the fact that one of the eight seeded cases contributed an excessive amount of precipitation. In the arithmetic mean this one case produces a greater effect than it does in the geometric mean which tends to give less relative weight to the heavy precipitation cases.

The fact that the two means give different results does not mean that one is superior to the other. One can argue logically in favor of either kind of averaging. The important thing to remember is that the use of logarithms was established in advance of the experiment and was not introduced after the data had been examined. In any case it is clear from the confidence limits that the difference between the means is not significant at the 95% level.

The variance of R_t is so large that the experiment provides virtually no information with respect to target area effects.

An analysis was also carried out, as an afterthought, of the precipitation, in the target area during the first six hours of the seeding period. The average target hour precipitation during these first six hours will be denoted $R_t + 6$. The dry ice seeding was generally carried out during these six hours.

As covariates for $R_t + 6$, we used the M - index and the precipitation in the six hours prior to seeding in the target area. (From table 2, Chapter II, it can be seen that in the seeded cases the arithmetic mean target area precipitation decreased from 0.161 inches before zero hour to 0.111 inches after zero hour while in the unseeded cases the arithmetic mean target area precipitation increased from 0.084 inches before zero hour to 0.116 inches after zero hour.)

The means and confidence limits for $R_t + 6$ are shown in table 10.

Table 10. Means and Confidence limits for $R_t + 6$. (inches)

Experiment TWO only

	Able	Baker
Observed Arithmetic Mean	0.111	0.116
Observed Geometric Mean	0.066	0.064
Adjusted Geometric Mean	0.070	0.061
95% Confidence Limits on ratio of means	$0.32 < \frac{A}{B} < 4.06$	

The difference of observed arithmetic means of $R_t + 6$ is less than 5% of the mean. The difference of observed geometric means is about 3% of the mean. The adjustment increases the difference to about 14% of the mean with more precipitation indicated in the seeded than in the unseeded cases. (The adjustment upward of the Able precipitation is due to the fact that the geometric mean of the precipitation prior to zero hour was greater in the unseeded than in the seeded cases although the reverse was true for arithmetic means.) However, the confidence interval is so large that the experiment again provides practically no information with respect to small scale target area effects.

H. Summary of statistical results. Although the precision of the experiment has still not reached a satisfactory level, it is possible to state some conclusions from the statistical analysis.

First of all it must be stated that there is no statistical evidence in any of the variates that the seeded and unseeded samples were drawn from different populations. None of the differences between the sample means were found to be significant.

With regard to the large scale precipitation in the seeded area, more precipitation fell (after adjustments) in the unseeded cases than in the seeded cases. The difference between the precipitation in the seeded and unseeded cases was about the same in both experiments despite the increase in dry ice output in experiment TWO. However, the best estimates of adjusted rainfall indicate that the rainfall was only about 5% higher in the unseeded than in the seeded cases with about one chance in twenty that seeding either increased or decreased the rainfall more than about 35%.

A similar result was found for the large scale precipitation downwind of the seeded area after the end of the seeding. For this region the best estimates of adjusted rainfall indicate that tho rainfall in the unseeded cases was 40% higher than in the seeded cases. (The difference between the precipitation in the seeded and unseeded samples in this region was greater in experiment TWO.) There is about one chance in twenty that the true ratio of seeded to unseeded precipitation lies outside the interval between 32% and 139%.

With regard to small scale precipitation there is very little information. In the twenty-four hours following seeding the (adjusted) precipitation in the target area was greater in the unseeded cases whereas in the first six hours of this period the precipitation was greater in the seeded cases. As shown by the broad confidence intervals, no significance can be attached to these differences.

When we consider the four precipitation variates together, it is clear that we have no reason to believe that the seeding either increased or decreased the precipitation.

The difference between the sample means of the pressure variates were uniformly small and reversed in sign between experiments ONE and TWO. The mean value of the maximum 24-hour sea level pressure change following zero hour was about -20 millibars. There is only about one chance in twenty that the difference between the true means of the maximum pressure change in the seeded and unseeded cases exceeded about 5 millibars.

Again, it is clear that we have no reason to believe that the seeding had any effect on the pressure at sea level. At least, in two years of experimentation no effect could be detected.

While the statistical analysis of the experiment does not permit us to reject the null hypothesis (i.e., that there is no effect of seeding on the large scale test variates), it does not preclude the possibility that effects exist. For example, it is possible that cloud seeding may produce different effects in different situations. With certain cloud temperatures, cloud structures and synoptic situations, a given seeding treatment may increase precipitation, whereas the same seeding treatment may, in another situation, diminish precipitation.

If the effect of seeding is of this more-or-less random nature, it will not be revealed by a comparison of means. However, one would expect the sample variances to be greater in the seeded than in the unseeded samples. As an after-thought, ratios of the Able to Baker sample variances were calculated for all seven test variates. In the case of the rainfall, variance ratios were computed for both rainfall and logarithm of rainfall. The variance ratios and values of the variance ratios required for significance at the 5% level (see Snedecor, G. W., Statistical Methods. Iowa State College Press 1946) are given in table 11.

Table 11. Ratios of Able to Baker Sample Variances (F) and Variance Ratio Required for Significance at the 5% level (F. 06)

Variate	Experiment	F	F.05
R_1	ONE	0.9	3.2
	TWO	1.2	3.8
	ONE + TWO	1.0	2.2
Log R_1	ONE	1.2	3.2
	TWO	2.2	3.8
	ONE + TWO	1.6	2.2
R_2	ONE	3.25	3.2
	TWO	0.3	3.8
	ONE + TWO	1.2	2.2
Log R_2	ONE	2.8	3.2
	TWO	1.5	3.8
	ONE + TWO	2.05	2.2
R_t	TWO	2.4	3.8
Log R_t	TWO	3.4	3.8
P_1	ONE	2.3	3.2
	TWO	1.2	3.8
	ONE + TWO	1.7	2.2

Table 11. (Continued)

Variate	Experiment	F	$F_{.05}$
P_2	ONE	3.0	3.2
	TWO	1.5	3.8
	ONE + TWO	2.65	2.2
P_{m1}	ONE	0.75	3.2
	TWO	1.1	3.8
	ONE + TWO	0.85	2.2
P_{m2}	ONE	1.2	3.2
	TWO	1.3	3.8
	ONE + TWO	1.4	2.2

Of the twenty-six variance ratios calculated only two reached the significant level. Since there is one chance in twenty of finding a variance ratio at least as large as $F_{.05}$ with random samples, no significance can be attached to these two values, especially as this whole computation was an afterthought anyway.

Whether or not the fact that most of the variance ratios are greater than unity (indicating larger variance in the seeded cases) is a real treatment effect, can only be determined by further experiments.

Chapter V. Conclusions and Recommendations.

At the end of experiment ONE we concluded that, while no effects of the cloud seeding could be detected, we still could not rule out any of the possibilities that the effect was negative, positive or zero. Because of the small number of experimental cases and the large residual variance, it was not possible to make a statement with sufficient precision to be of practical value. The confidence intervals were broad enough to include both positive and negative effects of great magnitude.

It was expected that the addition of more covariates in experiment TWO would reduce the residual variance and permit a more precise statement to be made with regard to the effects of seeding. The addition of T and L as covariates did, in fact, diminish the residual variance. However, the improvement was smaller than had been hoped for and was offset by the loss of four degrees of freedom which we could ill afford to lose. (One degree of freedom is lost by the addition of each new covariate and two more degrees of freedom are lost because there were only eight pairs of cases in two compared with ten pairs of cases in ONE.) Therefore, it was not possible to make any more precise statement from TWO alone than from ONE alone.

The combination of data for ONE and TWO increased the precision of the experiment to a point where a statement of some practical value could be made. For example, in the case of R_1, the length of the 95% confidence interval for the difference of logarithms of R_1 (between Able and Baker samples) was 0.62 in ONE and 0.56 in TWO. For ONE and TWO combined, the length of the interval was 0.37. Thus, with two years of data, we are rather confident that seeding did not increase precipitation more than 35% (see Table 3), whereas with one year of data we could only state, with the same confidence, that seeding did not increase precipitation more than 80%.

With respect to large scale effects of seeding, the very small differences between means of the test variates for Able and Baker samples offer little hope that these effects can be detected or indeed exist. Thus far, the confidence intervals appear to be closing in on a difference of means that is very nearly zero, so that it seems unlikely that seeding had any large scale effect on the weather.

Of course, it is desirable that the seeding question be answered with greater precision than we have yet achieved. Therefore it is of some practical importance to estimate how much time is required to achieve any desired level of precision. With two years of data it is possible to make a reasonable estimate of this time.

The length, K, of the confidence interval, which is a convenient measure of the precision of the experiment, is given by

$$K = 2 \; t_{\alpha} \left(\frac{2 \cdot S^2}{n} \right)^{1/2} .$$

where t_{α} is the tabulated value of t corresponding to a probability α , S^2 is the residual variance and n is the number of pairs of cases in the experiment.

We will assume that the residual variance, based on the two years of data, will remain essentially constant with the addition of more data. Then, since t depends only on the number of degrees of freedom, we can calculate K for any value of n .

We will consider how much additional precision we can expect to achieve with one more year of experimentation and also how many more years of experimentation are needed in order to reach a given level of precision. For the purpose of these estimations we will use the variates R_1 and P_{m1}. The results will be quite similar for the other variates.

With the three covariates M, T and L, the length of the 95% confidence interval, K, for the difference of means of the logarithms of R_1 was found to be 0.31 for eighteen pairs of cases. (With only M as covariate, K is 0.37 and with M and T, K is equal to 0.34. Thus each covariate does contribute to the precision of the experiment.) Assume that another year of experimentation will add nine pairs of cases. Then, with the aid of the t - table, we find that the confidence interval will shrink to 0.25. A confidence interval of length 0.31 in the logarithms corresponds to a 43% increase or 30% decrease in the rainfall (if the confidence interval is centered on zero.) A confidence interval of length 0.25 in the logarithms corresponds to a 33% increase or a 25% decrease. Thus one additional year of data will increase the precision of the experiment by an amount corresponding to about 10% effect.

If we wish either to detect or exclude the probability of a 20% effect of seeding on rainfall, we must shrink the confidence interval on the logarithm to 0.16. Since the confidence interval varies inversely as the square root of the number of cases (the variation of t is rather small except for very few degrees of freedom), we find that this requires a total of about sixty-seven pairs of cases. Assuming that we acquire nine pairs each year, this level of precision would be reached after about five more years of experimentation.

It must be remembered that these calculations are based on the assumption that the residual variance will not change with the addition of more data. Actually it may be possible to reduce the variance through the use of better covariates, although it must also be recognized that the selection technique could lead to an increase in the variance.

In the case of P_{ml} the calculation shows that another year of experimentation would reduce the confidence interval from about 10 to about 8 millibars. Expressed in terms of the relative effect, this means that while now we are rather confident that seeding did not alter the maximum pressure change more than 26%, one more year of experimentation would probably allow us to detect or exclude the probability of a 21% effect.

If we set as our goal a confidence interval of 5 millibars, i.e. if we are interested in detecting effects greater than $\pm$ 2.5 millibars or about 13% of the present mean value of P_{ml}, we would require a total of 76 pairs of cases or about six more years of experimentation.

It is apparent from the results of the experiment thus far that we have no reason to believe that cloud seeding produces any large scale weather modification. If we continue the experiment for one more year, we may be able to state our result with greater precision. However, some uncertainty will still exist and many years of experimentation will be needed in order to reduce this uncertainty appreciably. Such an extended program is hardly justified by the results obtained thus far and is not recommended.

The experiment has answered certain questions connected with cloud seeding. It has left others unanswered and has raised some new questions.

We have found that the seeding techniques employed in the experiment do not produce effects which are so large and widespread that they can be detected against the natural background variability of the atmosphere. However, we have not ruled out the possibility that effects of this magnitude may be produced by a different seeding technique. It is possible that a greater seeding rate, perhaps with 50 pounds of dry ice per mile, and greater areal coverage might produce the desired result. Of course, to test this hypothesis it would be necessary to carry out the same kind of randomized experiment that Project SCUD has conducted for the past two years. We do not propose that this be done; but, if further field experiments are to be carried out, we do recommend the use of more aircraft and a greater output of seeding material.

The relatively low precision of the experiment is indicative of the fact that our knowledge of and ability to predict cyclogenesis and cyclonic weather are inadequate. In the course of the experiment the existing cyclone models proved to be generally unsatisfactory both for descriptive and prognostic purposes. It should be possible, with the aid of the data collected during the experiment, to construct a set of realistic east coastal cyclone models. These will be of assistance in forecasting and will also help to increase the precision of future meteorological experiments.

Appendix

Description of Cases and Seeding Operations.

Experiment TWO

During the period December 1953 - April 1954 sixteen cases of potential cyclogenesis were selected for seeding.

Approximately 500 gallons of silver iodide solution were consumed in the eight Able cases at the rate of about 1.3 quarts per hour per station.

The aircraft dispensed a total of about 44,000 pounds of dry ice on their seeding missions with an average of 5500 pounds per Able mission. The average duration of seeding was 103 minutes per plane per case in the Able cases. The average duration of simulated seeding in the Baker (unseeded) cases was 93 minutes per plane per case.

The average flight altitude for the Able flights was 18,000 feet with an average flight level temperature of -16 degrees C. For the Baker flights the average flight altitude was 16,500 feet with an average flight level temperature of -13 degrees C.

In general it can be stated that the seeding condition in the Able and Baker samples were comparable.

The sixteen cases of experiment TWO are described below. Included in the description of cases are the surface weather maps for zero hour and zero-plus-24 hours and the flight cross-sections prepared by the flight aerologists. The target areas are shown on the zero hour maps. Greenwich Mean Time (Z time) is used throughout.

The in-flight observations are of sufficient interest to warrant detailed analysis and discussion. In the interests of brevity, however, this analysis is not included in this report but will be made the subject of a separate study.

1. Case No.22, Able. (Figs. 14 - 15).

A. Zero hour: 1830 Z, 4 December 1953.

B. Target area: 4.

C. Ground seeding: Stations 1A, 1C, 1D and 2A (see figure 2, report No. 1) did not operate. Station 5A operated until 1330 Z. The remaining stations operated on schedule.

D. Flight operations:

Red flight was not completed due to failure of de-icer and accumulation of moderate rime near New Bern at 1813 Z. Plane returned to Jacksonville at 18,000 feet in clouds at temperature -10° C. Seeding was conducted between New Bern, N.C. (1813 Z) and Georgetown, S.C. (1935 Z) in area 3. Seeding time: 70 minutes. Amount dispensed: 2475 lbs. No flight cross section was prepared.

Blue flight returned to Jacksonville at 1850 Z before reaching target area due to mechanical trouble. 2475 lbs. of dry ice were dispensed in 33 minutes between Savannah (1730 Z) and Brunswick, Ga. (about 1820 Z) (area 1). "Aircraft was in clouds during dispensing operation at altitude ranging from 19,000 to 10,000 feet and temperatures ranging from -9 to -5°C." No cross section was submitted. (Note that seeding rate was more than 30 lbs. per mile).

Green flight was shifted to blue track and, beginning at 1835 Z, dispensed 2475 lbs. in 67 minutes. This was more than double the specified seeding rate and resulted in premature exhaustion of the dry ice supply.

For further discussion of this operation see Chapter III.

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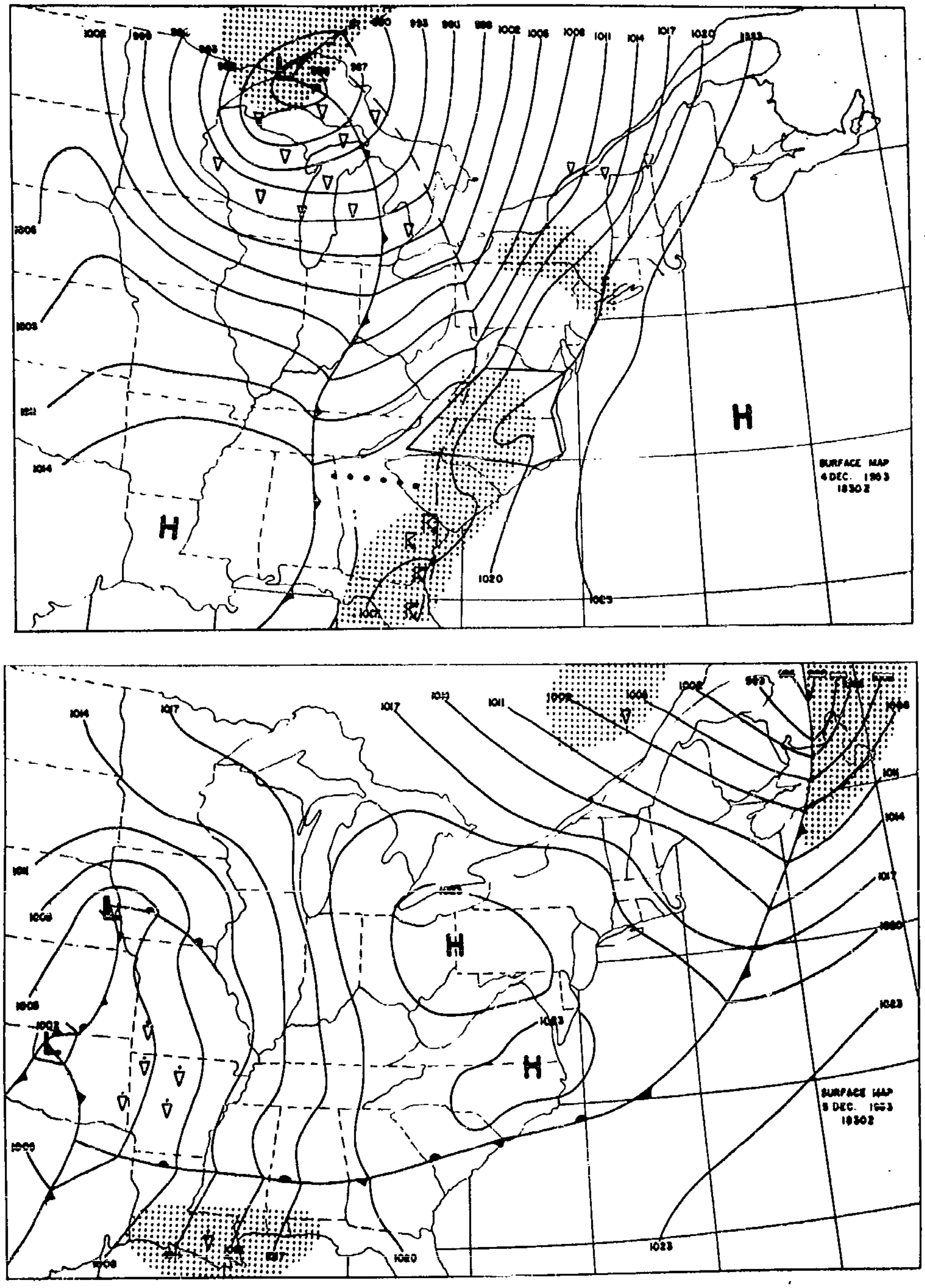

Fig. 14. Case No. 22. Zero hour: 1830Z, 4 December 1953. Able.

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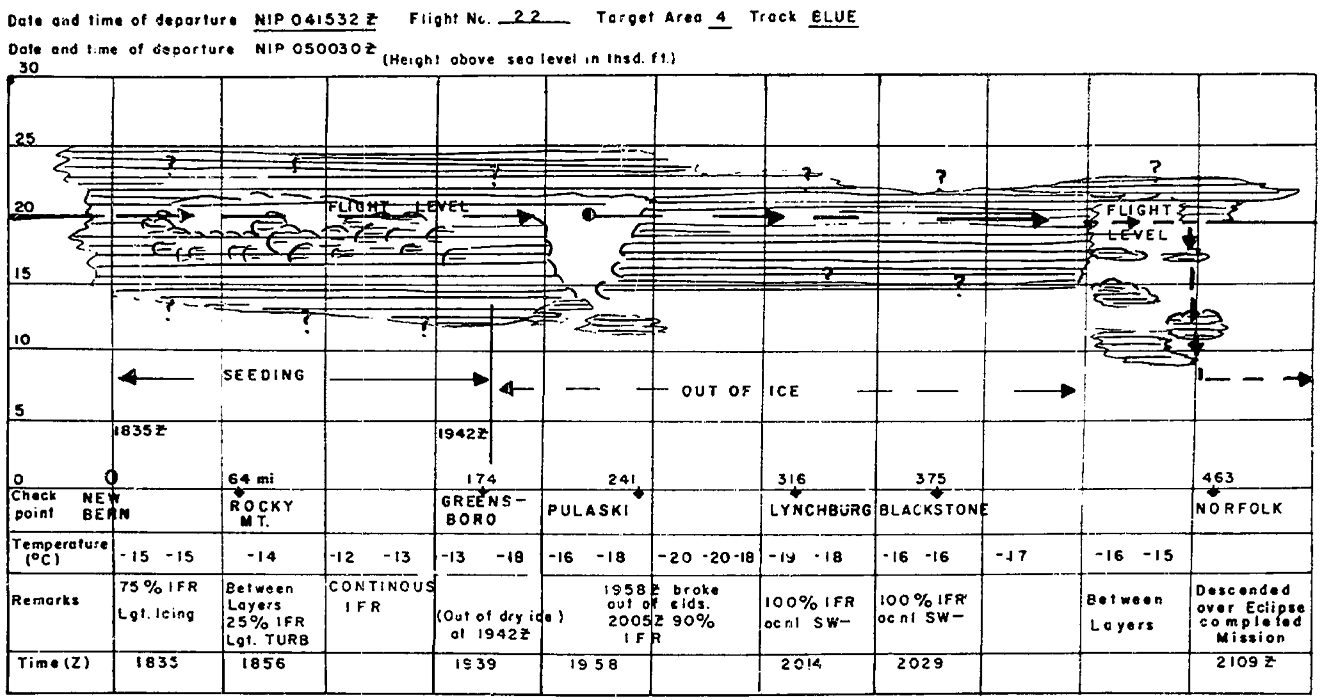

Fig 15. Flight cross-section. Flight No. 22. Blue track. 4 December 1953.

2. Case No. 23, Baker (Figs. 16 - 17).

A. Zero hour: 1830 Z, 9 December 1953.

B. Target area: 4.

C. Flight operations:

Flight was conducted on blue track at varying altitudes. Simulated seeding was carried out for 40 minutes before plane was forced to descend below melting level due to pilot's ear trouble.

3. Case No. 24, Able (Figs. 18 - 21).

A. Zero hour: 1230 Z, 12 December 1953.

B. Target area: 2.

C. Ground seeding: All stations except 10 operated on schedule.

D. Flight operations:

Red, Blue and Green flights began seeding at 1105 Z, 1122 Z and 1122 Z respectively. The flight time was advanced because of the forecaster's expectation that seeding conditions would deteriorate during the period.

At 1127 Z Red flight began descent to 8000 feet to avoid heavy clear icing at 18,000 feet resulting from failure of de-icing equipment. 2475 lbs. of dry ice were dispensed in 58 minutes. During the first 15 minutes of seeding the normal rate of 5 lbs. per mile was used. Between 1120 Z and 1203 Z seeding was conducted as rapidly as possible to reduce airplane load.

Blue flight dispensed 2200 lbs. in 105 minutes. Moderate rime ice was encountered in all clouds at 18,500 feet.

Green flight dispensed 2475 lbs. in 125 minutes. Light rime ice was experienced in clouds at 20,000 feet.

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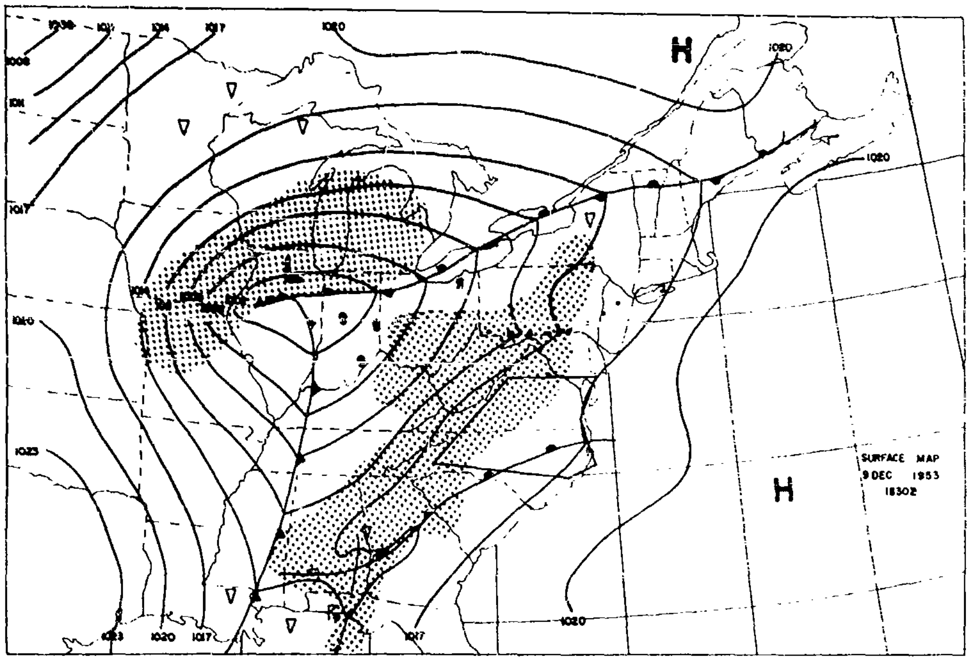

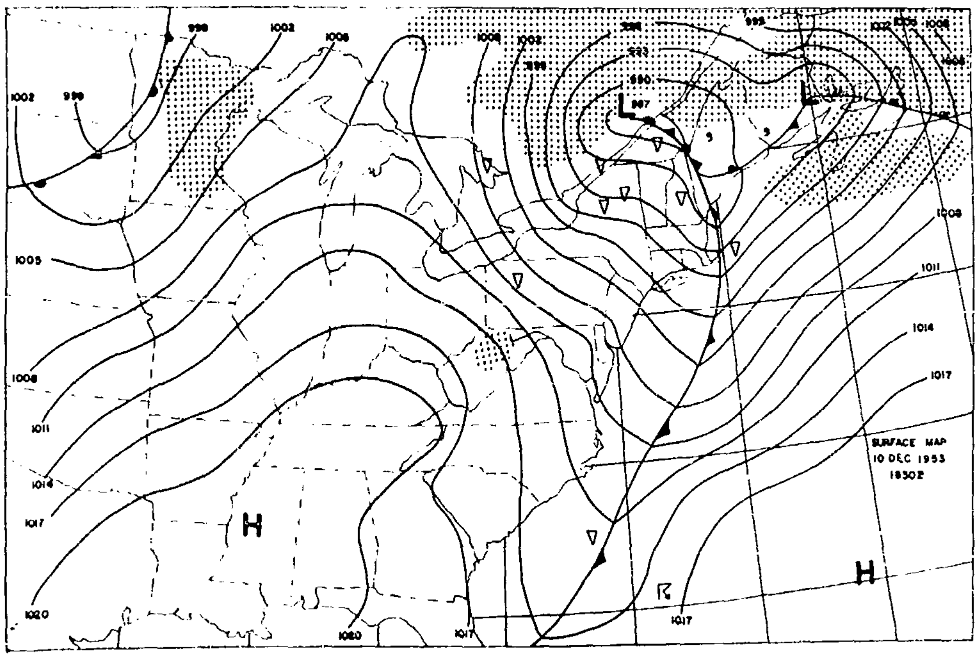

Fig. 16. Case No. 23. Zero hour: 1830Z, 9 December 1953. Baker.

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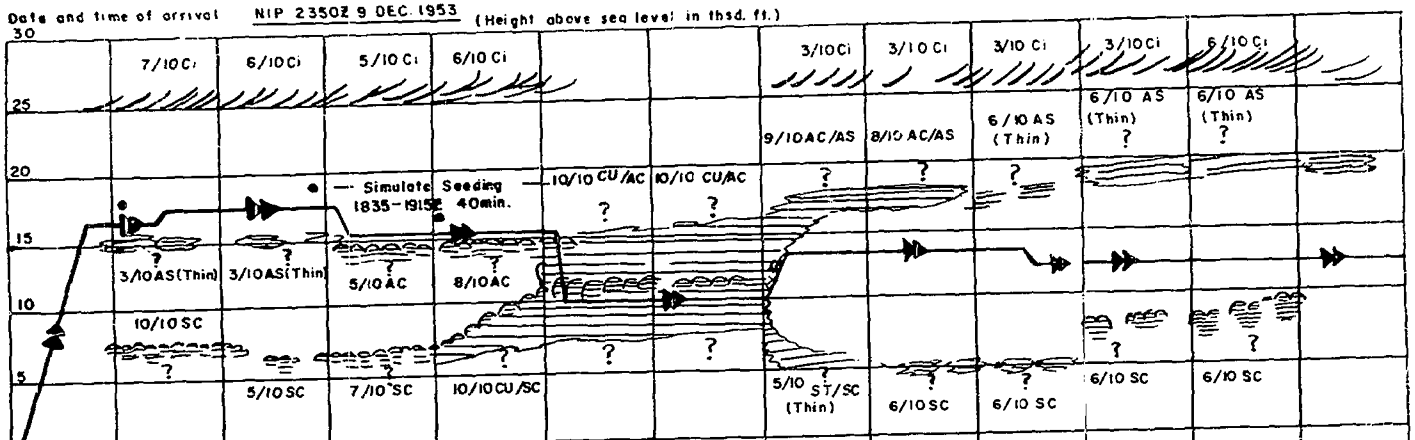
Date and time of departure NIP 1600Z 9 DEC. 1953 Flight No. 23 Target Area IV Track BLUE

Date and time of arrival NIP 2350Z 9 DEC. 1953 (Height above sea level in thsd. ft.)



Check point	New Bern	Rocky Mount		Greensboro		Lychburg	Blackstone		Norfolk		New Bern	
Temperature (°C)	−11	−12	−1C	−11	+5	+4	−1		−1		+3	
Remarks	17000	17500	15500 simulate seeding	15500 change Flight Plan (pilot ear trouble)	10000 in clouds Light rain ceased seeding	10000 in clouds Light rain	13000 wind: 220/80KTS.		13000–12000		12000	
Time(Z)	1756	1816	1835	1900	1930	1945	2000		2024		2113	

Fig. 17. Flight cross-section. Flight No. 23. Blue track. 9 December 1953.

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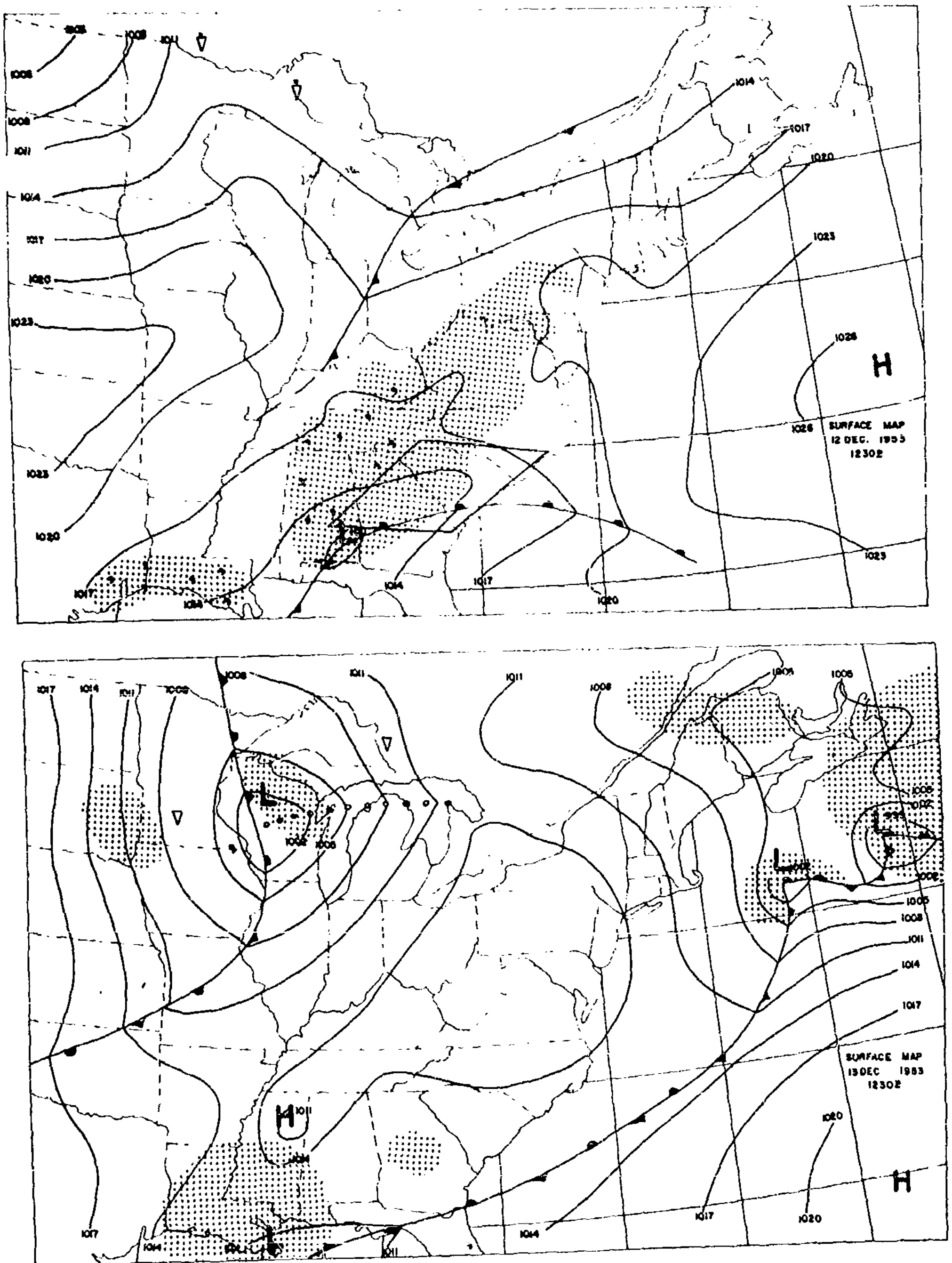


Fig. 18. Case No. 24. Zero hour: 1230Z, 12 December 1953. Able.

Date and time of departure. NIP 0957Z 12 Dec.1953 Flight No. 24 Target Area II Track Red

Date and time of arrival. NIP 1253Z 12 Dec.1953

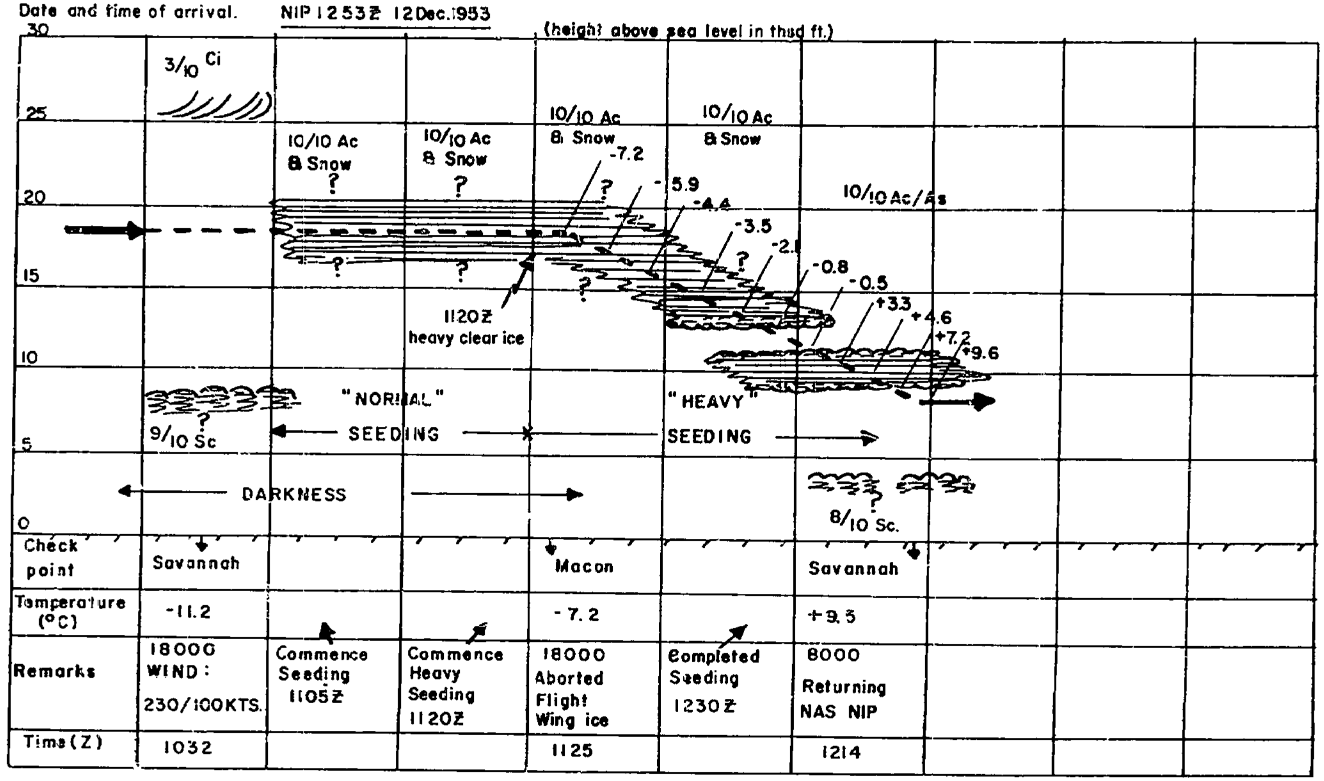


Fig. 19. Flight cross-section. Flight No. 24. Red track. 12 December 1953.

CONFIDENTIAL

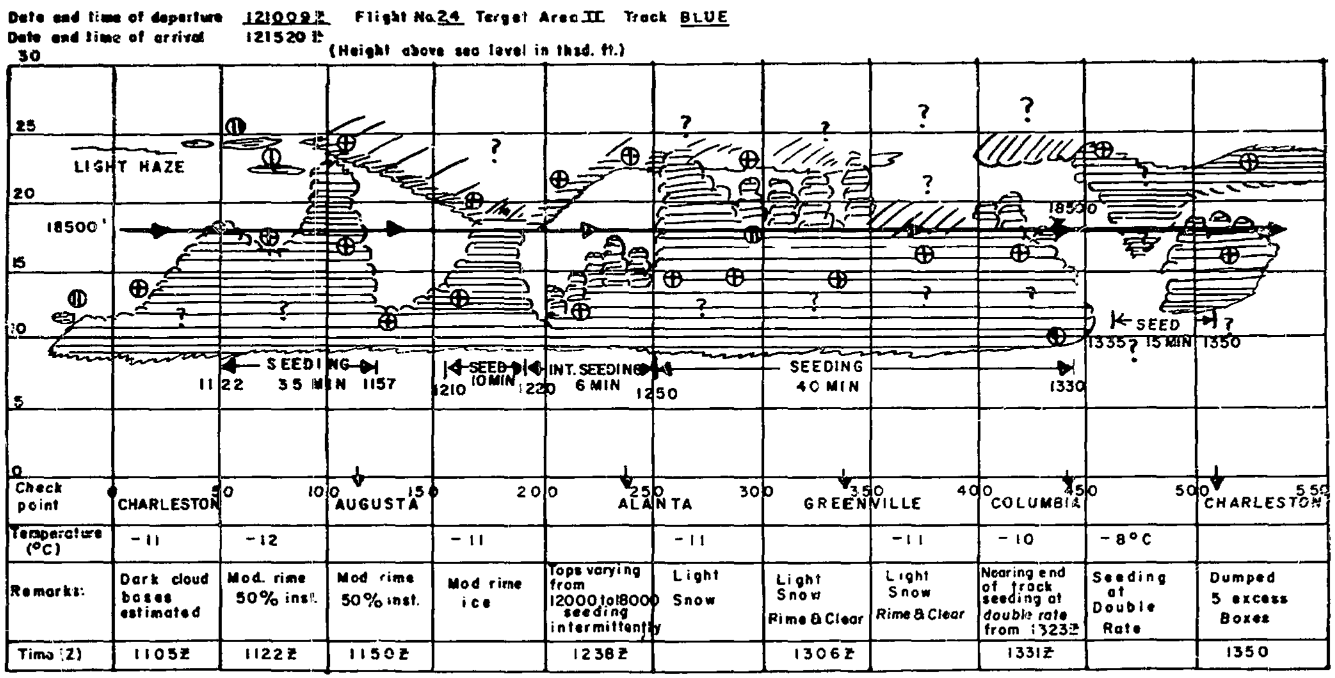
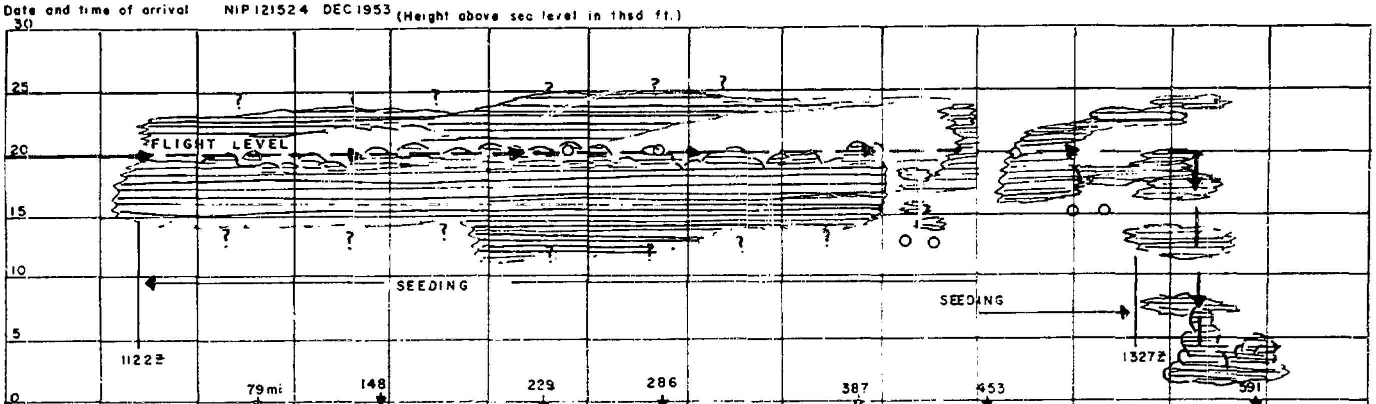


Fig. 20. Flight cross-section. Flight No. 24. Blue track. 12 December 1953.

Date and time of departure NIP 121009 DEC 1953 Flight No 24 Target Area II Track Green

Date and time of arrival NIP 121524 DEC 1953 (Height above sea level in thsd ft.)



Check point	CHARLESTON	FLORENCE	COLUMBIA		SPARTANBURG	CHAROLETTE		FAYETTEVILLE		WILMINGTON		CHARLESTON	
Temperature (°C)	-10 -12	-13 -13	-13 -13	-13 -13	-13 -13	-13 -13	-13	-13 -14	-14	-14 -15	-15 -15	-15 +13	
Remarks	DARK Stars vsbl. above lights vsbl. below	1122Z in clds Commence Operation	50-75% IFR Lgt Ice Lgt Turb Lgt Snow	75% IFR Lgt. Ice Lgt. Turb.	100% IFR Lgt. Icing Lgt Turb.	75% IFR Lgt. Icing Lgt Turb	Between Layers (sun ocnly-	Between Layers vsbl)	25% IFR	Between 25% IFR Lower Layers ocnly sctd to Broken winds 240/90		1327 out of ice supply 1337 Descending to 4000 Ft.	
Time(Z)	1111Z	1130Z	1202Z		1217Z	1228Z		1253Z		1315Z		1404Z	

Fig. 21. Flight cross-section. Flight No. 24. Green track. 12 December 1953.

4. Case No. 25, Baker (Figs. 22 - 23).

   A. Zero hour: 1830 Z, 10 January 1954.

   B. Target area: 5.

   C. Flight operations:

   Flight was conducted on Blue track at 17,000 feet. Simulated seeding was conducted for 90 minutes. Light rime was encountered in clouds.

5. Case No. 26, Baker (Figs. 24 - 25).

   A. Zero hour: 1230 Z, 15 January 1954.

   B. Target area: 5.

   C. Flight operations:

   Flight was conducted mostly at 17,000 feet on Blue track. Some ice was picked up over Norfolk at 16,000 feet at 1545 Z (temperature -12° C). Simulated seeding was carried out for 120 minutes.

6. Case No. 27, Able (Figs. 26 - 27).

   A. Zero hour: 1230 Z, 21 January 1954.

   B. Target area: 4.

   C. Ground seeding: All stations except 1B operated. Station 2A terminated at 2015 Z.

   D. Flight operations:

   Red and Green flights were cancelled because of mechanical troubles.

   Blue flight began seeding at 1840 Z at 17,000 feet. 1350 lbs. were dispensed in 75 minutes. No icing was reported.

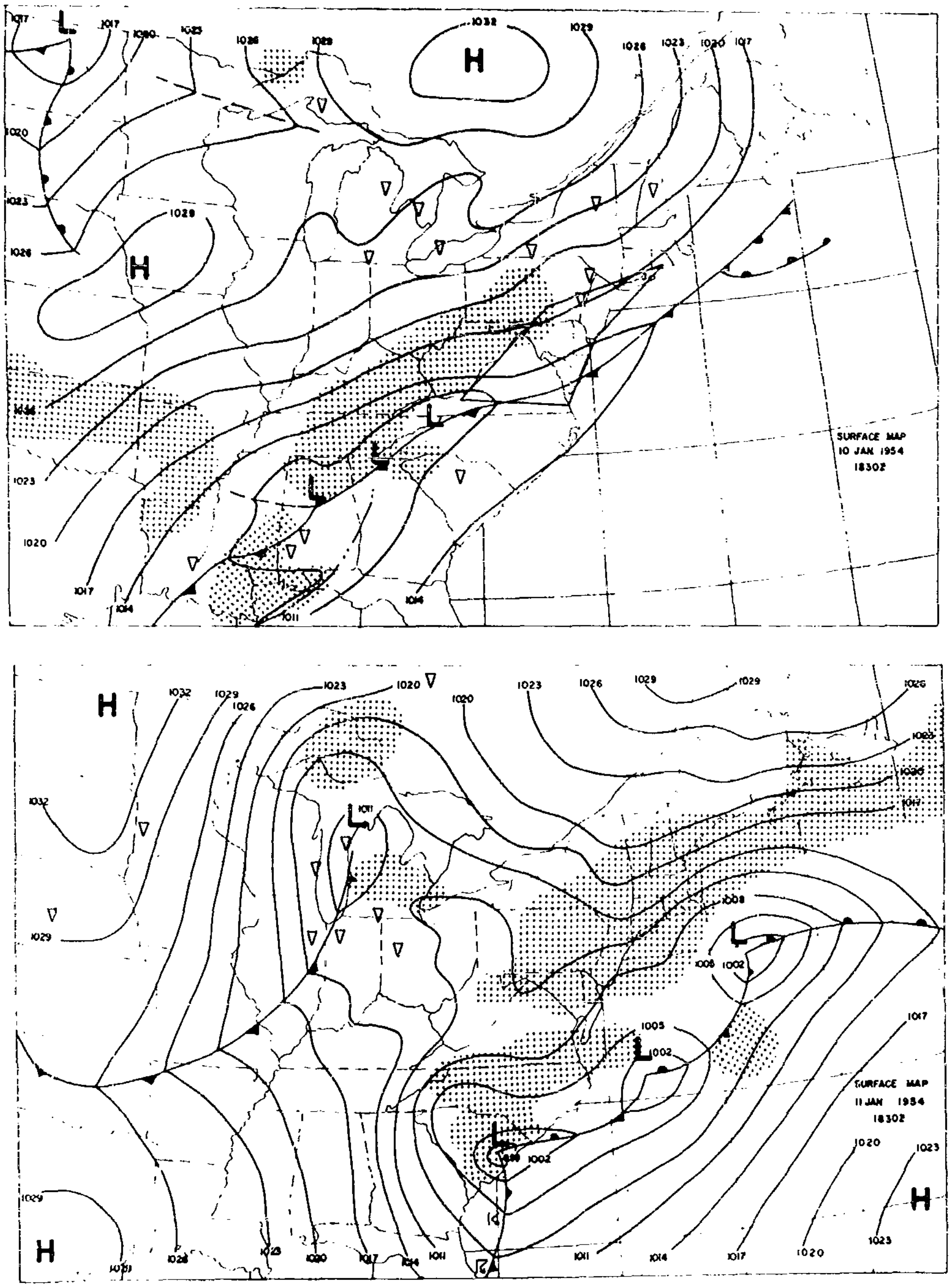


Fig. 22. Case No. 25. Zero hour: 1830Z, 10 January 1954. Baker.

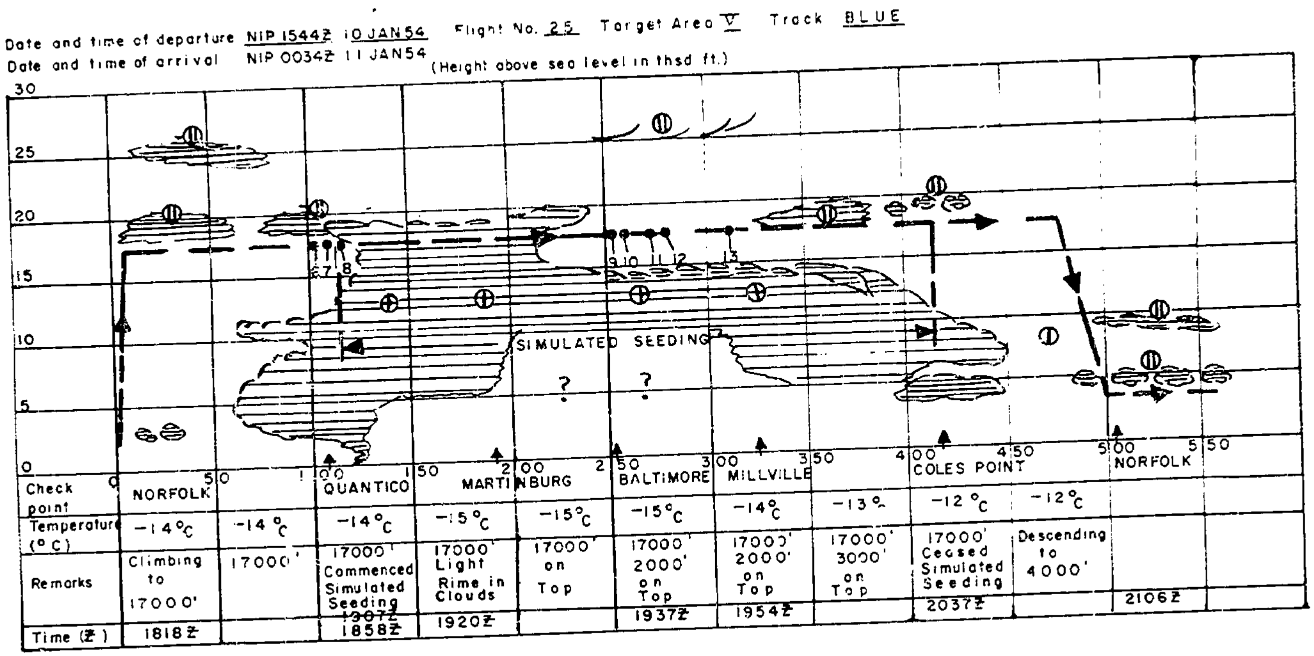


Fig. 23. Flight cross-section. Flight No. 25. Blue track. 10 January 1954.

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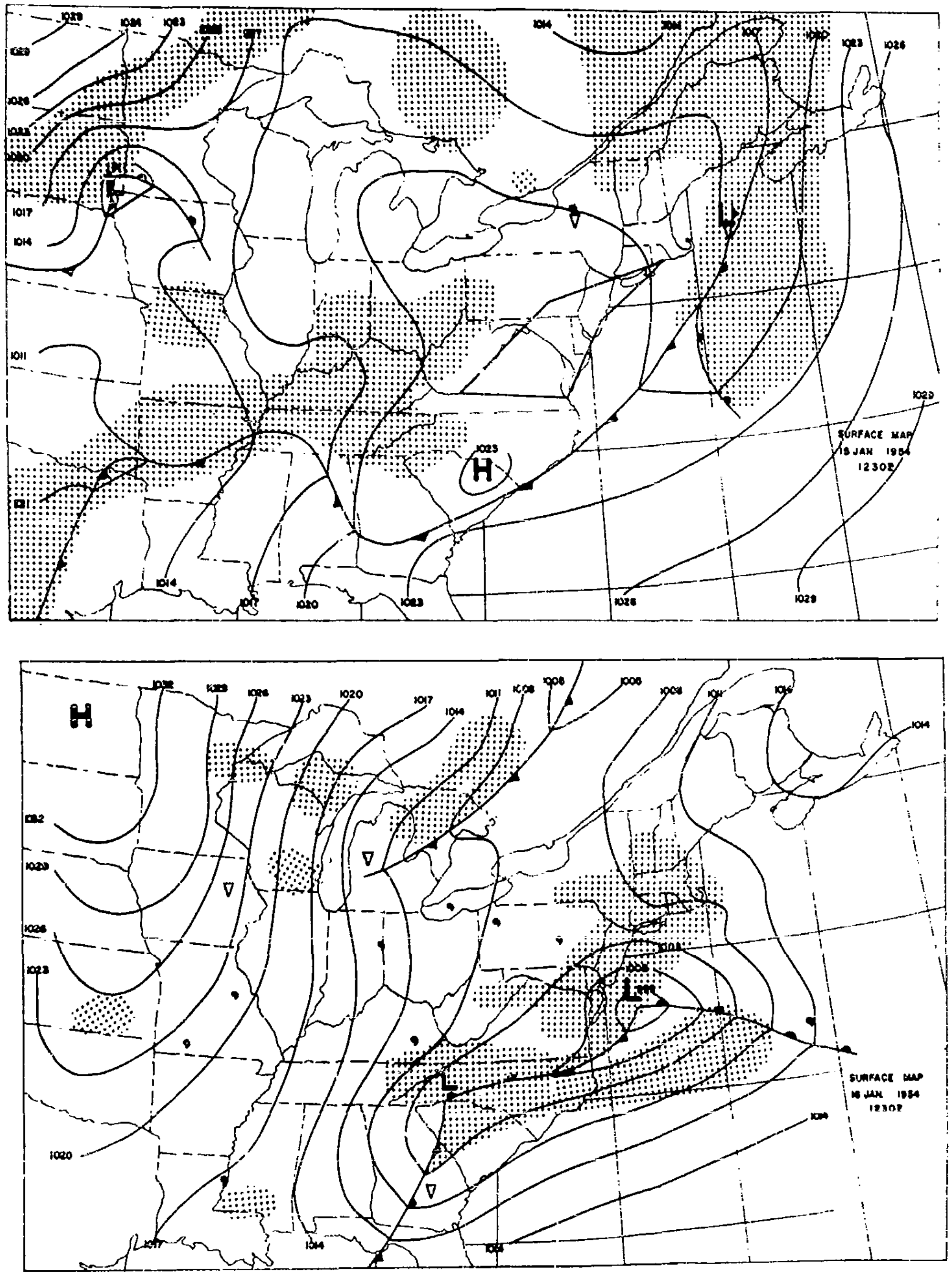

Fig. 24. Case No. 26. Zero hour: 1230Z, 15 January 1954. Baker.

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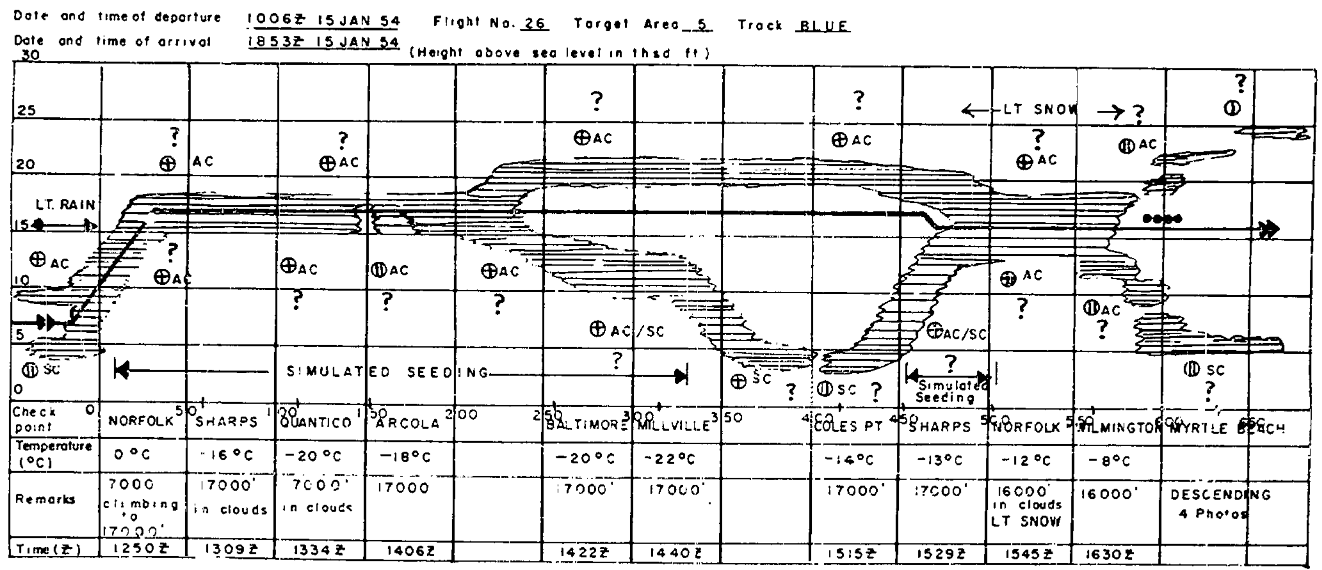

Fig. 25. Flight cross-section. Flight No. 26. Blue track. 15 January 1954.

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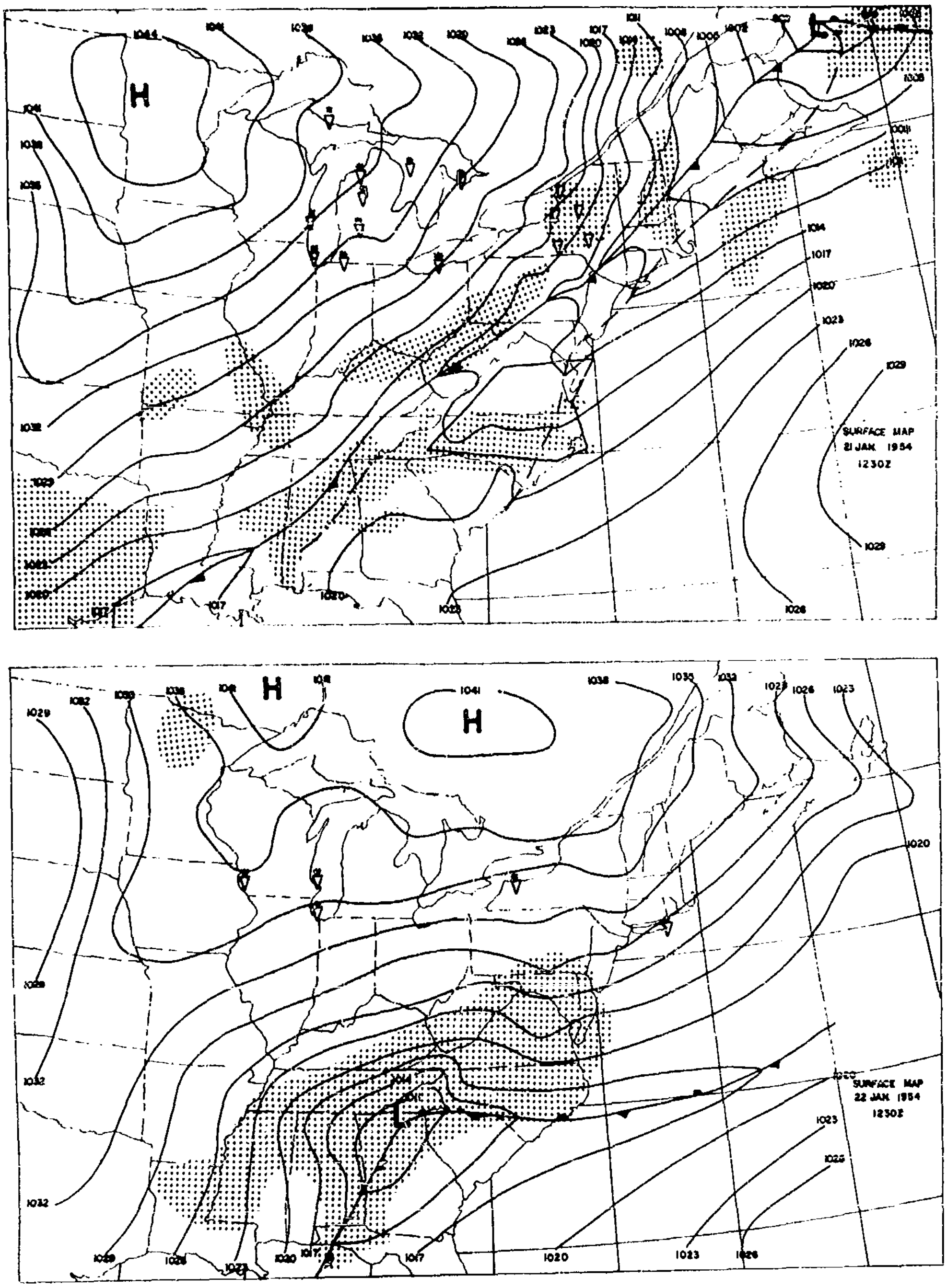

Fig. 26. Case No. 27. Zero hour: 1230Z, 21 January 1954. Able.

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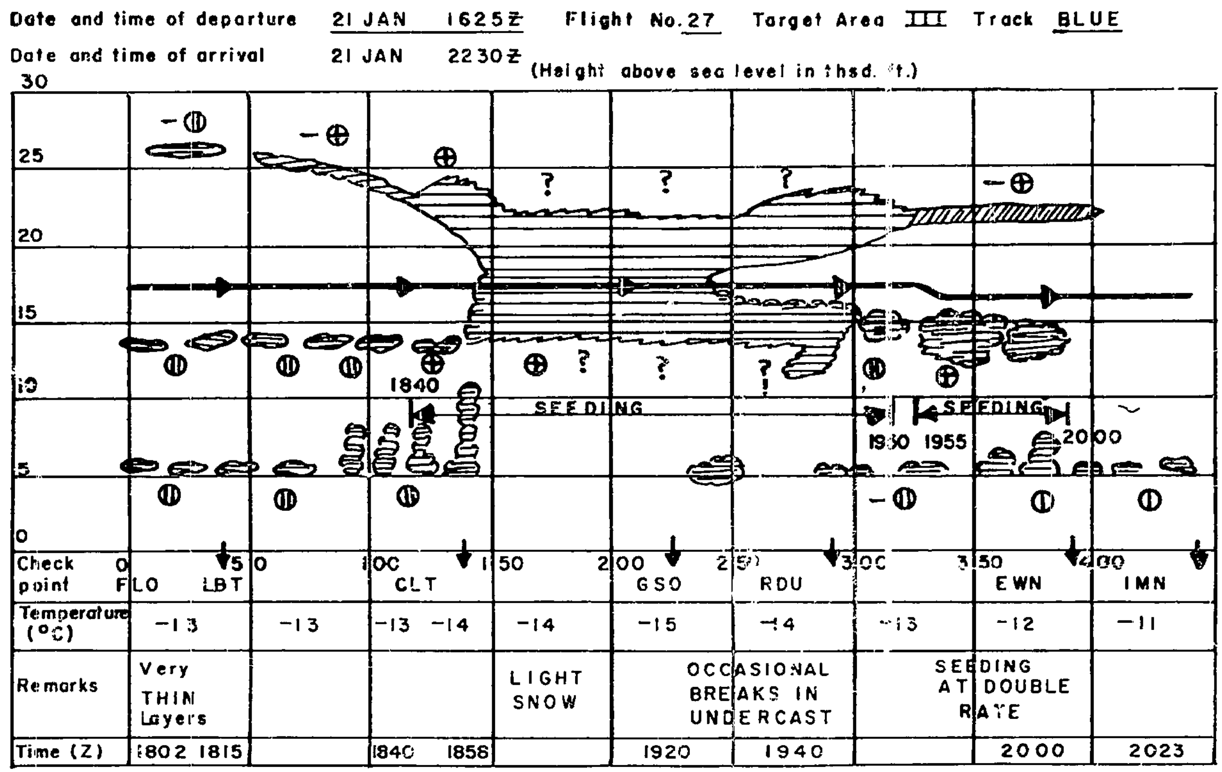

Fig. 27. Flight cross-section. Flight No. 27. Blue track. 21 January 1954.

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7. Case No. 28, Baker (Figs. 28 - 29).

A. Zero hour: 1830 Z, 27 January 1954.

B. Target area: 6.

C. Flight operations:

Blue flight was conducted at 19,000 feet. Simulated seeding was carried out for 114 minutes.

8. Case No. 29, Able (Figs. 30 - 33).

A. Zero hour: 1830 Z, 11 February 1954.

B. Target area: 4.

C. Ground seeding:

Only station 1B failed to operate.

D. Flight operations:

Red flight was conducted at 17,000 feet. Seeding began at 1850 Z. 2250 lbs. were dispensed in 131 minutes. No icing was reported in clouds.

Blue flight began seeding at 1850 Z at 18,000 feet. 2250 lbs. were dispensed in 132 minutes. No icing was reported in clouds.

Green flight began seeding on climb at 13,000 feet at 1908 Z. Remainder of flight was flown at 19,000 feet. 2250 lbs. were dispensed in 137 minutes. Flight was generally on top of clouds and only light rime icing was reported (at 12,000 feet near Norfolk at 1905 Z).

The apparent cloud modification reported on this flight is discussed in Chapter III.

9. Case No. 30, Able (Figs. 34 - 36).

A. Zero hour: 1830 Z, 20 February 1954.

B. Target area: 4.

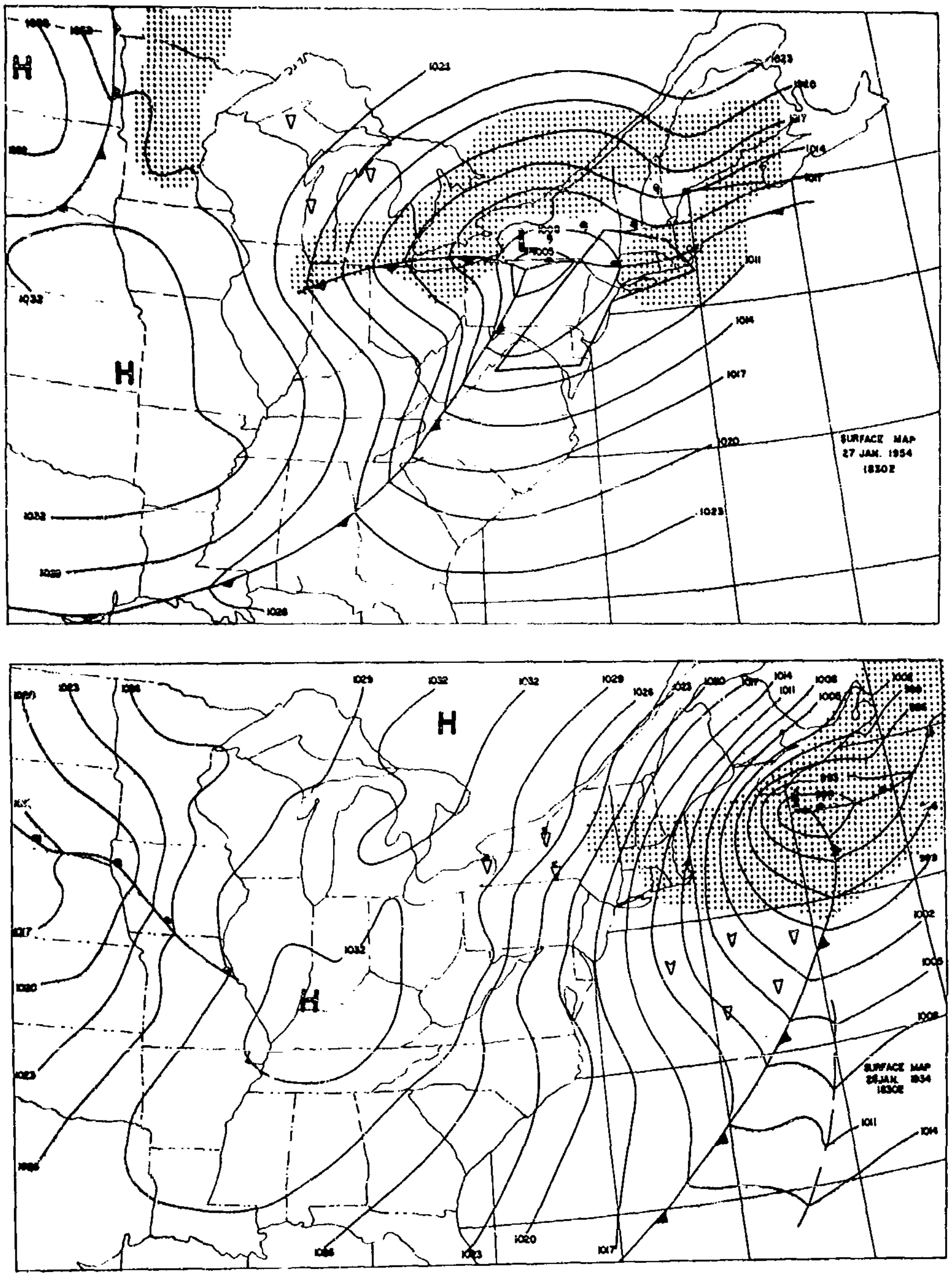

Fig. 28. Case No. 28. Zero hour: 1830Z, 27 January 1954. Baker.

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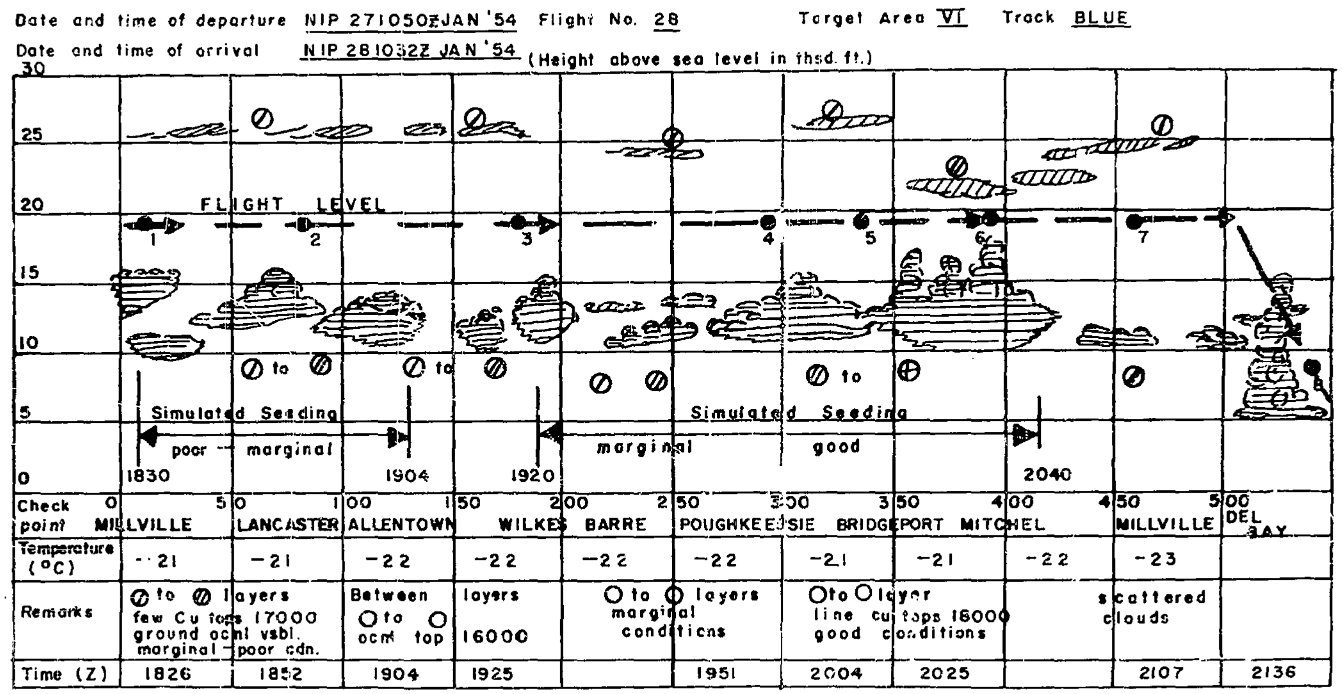

Fig. 29. Flight cross-section. Flight No. 28. Blue track. 27 January 1954.

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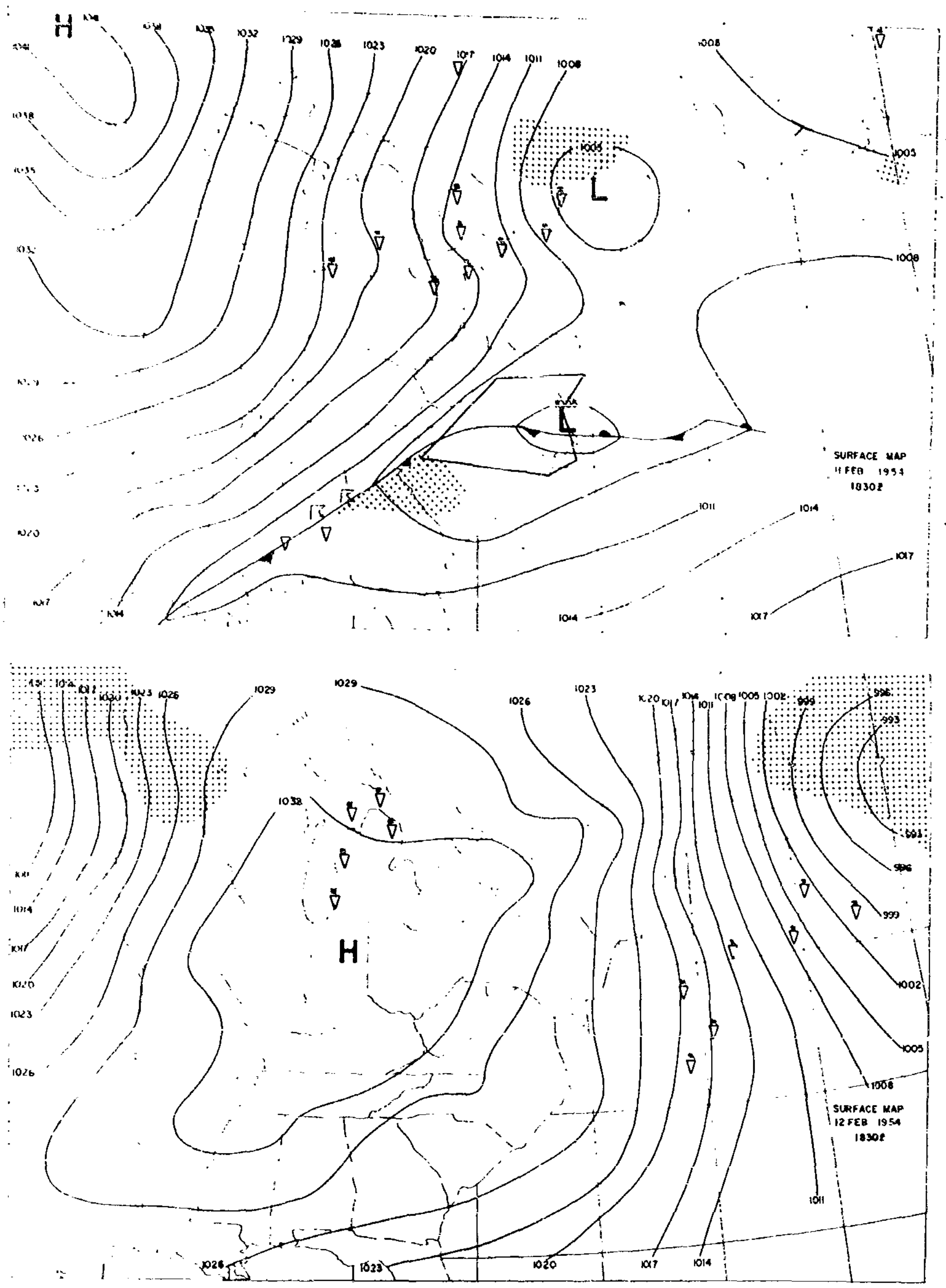

Fig. 30. Case No. 29. Zero hour: 1830 Z, 11 February 1954. Able.

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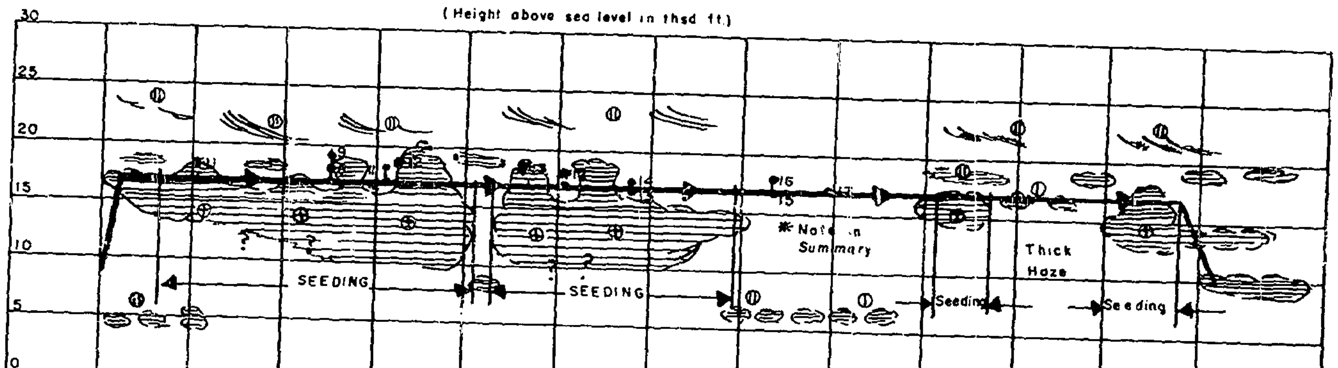
Date and time of departure NIP 1638 Z 11 FEB. '54 Flight No. 29 Target Area IV Track RED
Date and time of arrival NIP 0003Z 12 FEB. '54



Check point	0 Wilmington	50 Fayetteville	100	150 Charlotte	200 Hickory	250 Pulaski	300	350 Greensboro	400	450 Rocky Mount	500 New Bern	550 Wilmington	600
Temperature (°C)	0- (-17°)	-17°	-16°	-17°	-19°	-18°	-17°	-17°	-17°	-17°	-16°	-16°	
Remarks	Climbing start seeding 1850Z	17000'	17000'	17000	17000' stop seeding 1958Z start seeding 2000Z	17000' clear NW of Pulaski	17000' stop seeding 2045Z	17000' Cu buildups to South	17000' Cu buildups to South	17000' start seeding 2115Z stop seeding 2122Z	17000' Thick Haze	17000' Start Seeding 2146Z Stop Seeding 2157Z	
Time (Z)	1829	1855	1930	1943	1957	2025	2045	2048		2115	2133	2157	

Fig. 31. Flight cross-section. Flight No. 29. Red track 11 February 1954.

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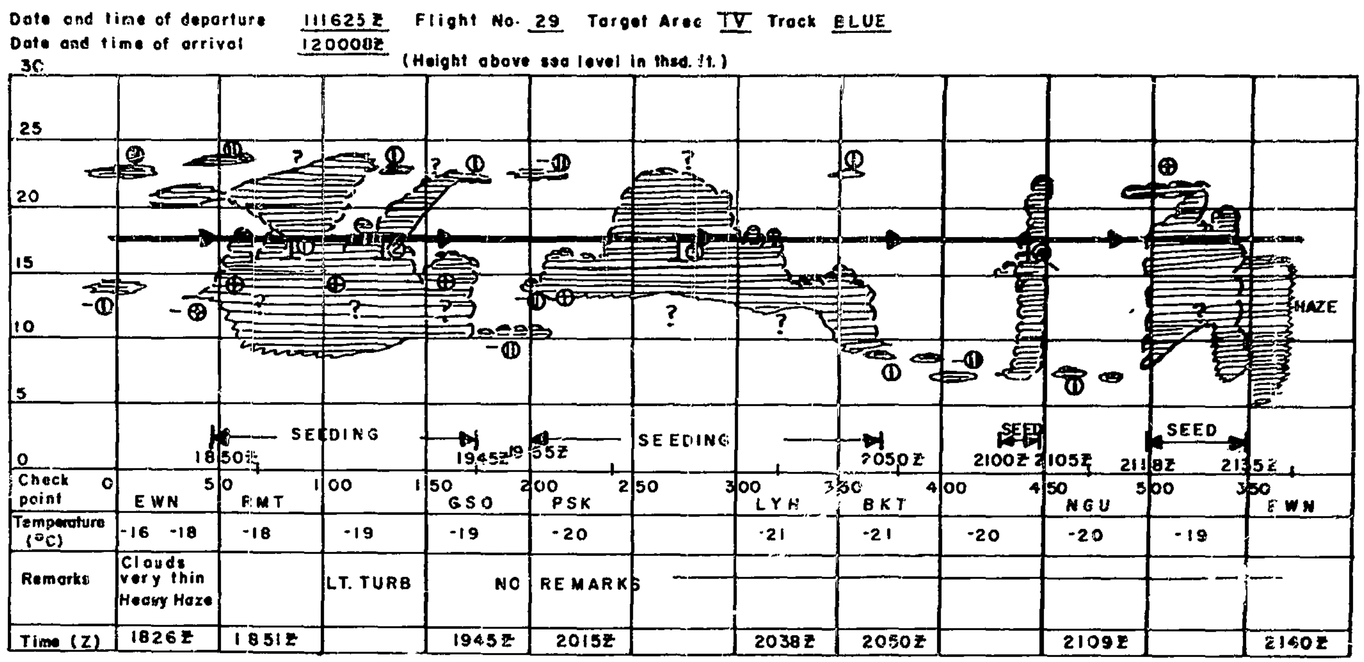

Fig. 32. Flight cross-section. Flight No. 29. Blue track. 11 February 1954

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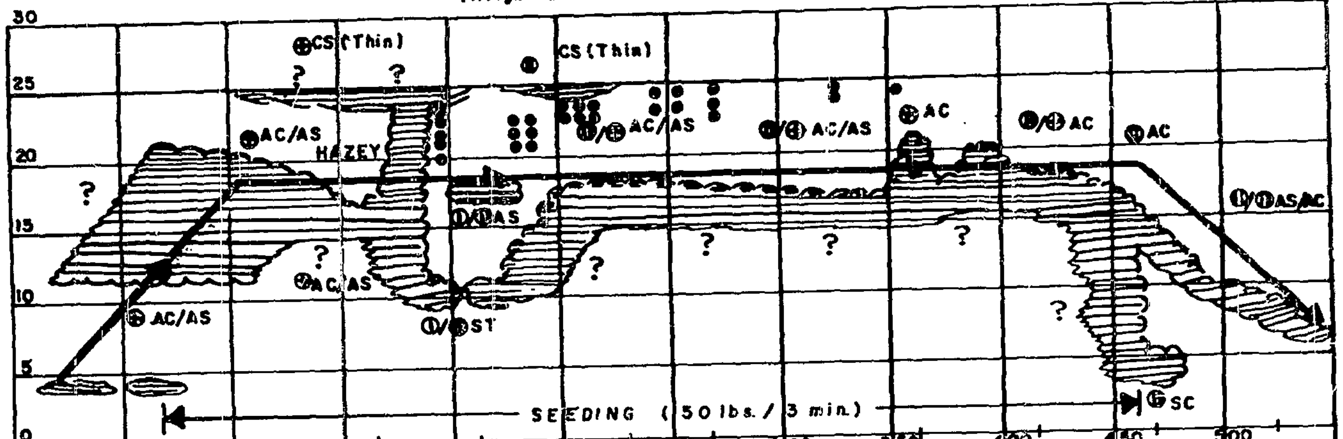
Date and time of departure 1616Z 11 FEB Flight No. 29 Target Area IV Track GREEN

Date and time of arrival 0056Z 12 FEB. (Height above sea level in thsd. ft.)



Check point	0 Norfolk	50 Richmond	100 Farmville	150 Lynchburg	200 Pulaski	250 Abeam Roanoke	300 Abeam Lynchburg	350 Gordonsville	400 Quartico	450 Sharps Int.	500 Norfolk
Temperature (°C)	-6	-23	-23	-24	-24	-23	-24	-24	-24	-24	-12.5
Remarks	12000 Climbing	19000	19000	19000 Trail of Buildups	19000 Trail from Red Track	19000 Trails of Buildups	19000 Trails of Buildups	19000 in Tops	19000 Trail of Buildups	19000 Descending	15000
Time (Z)	1900	1927	1948	2003	2033	2045	2054	2107	2116	2129	2143

Fig. 33. Flight cross-section. Flight No. 29. Green track. 11 February 1954.

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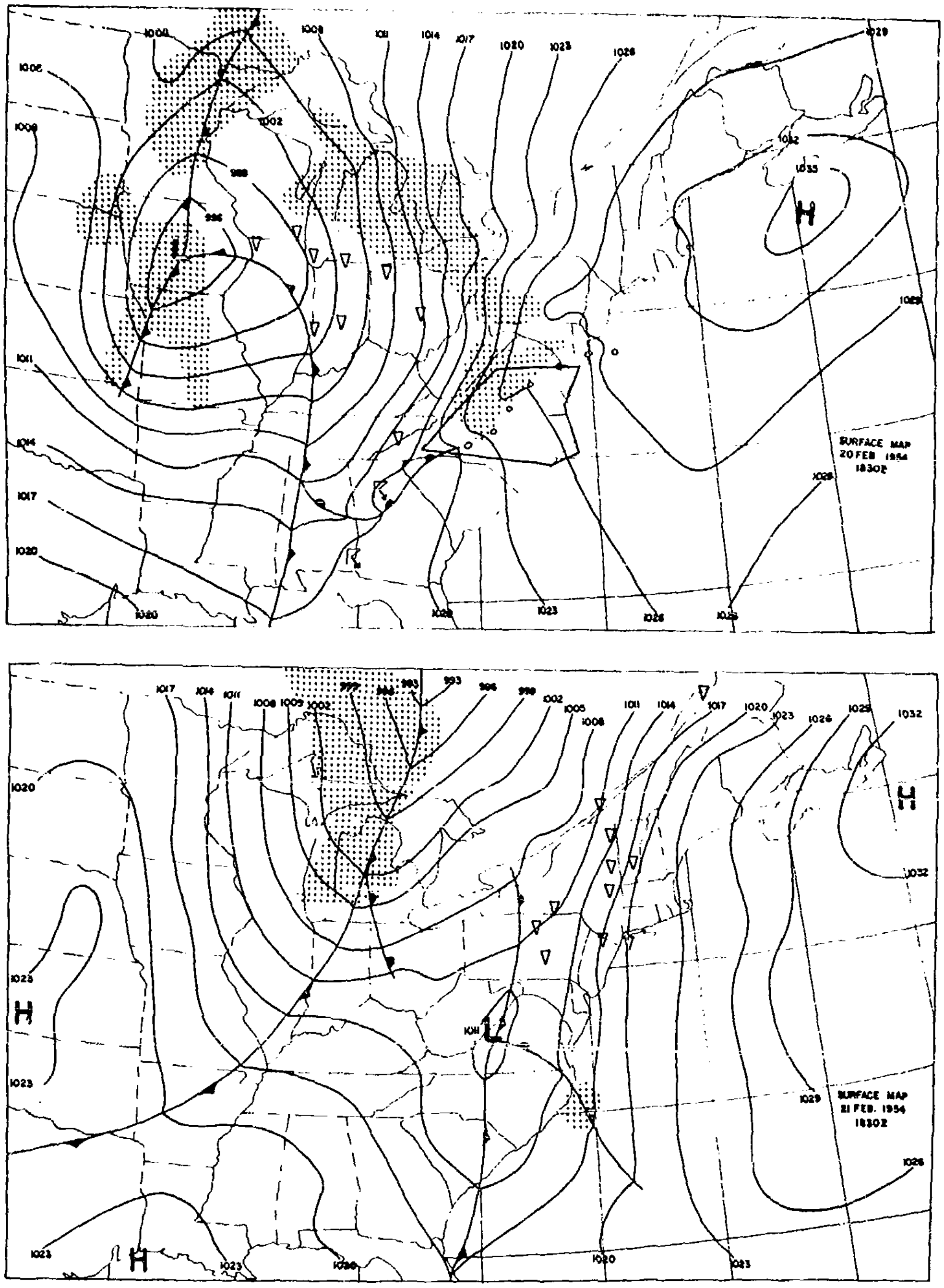

Fig. 34. Case No. 30. Zero hour: 1830Z, 20 February 1954. Able.

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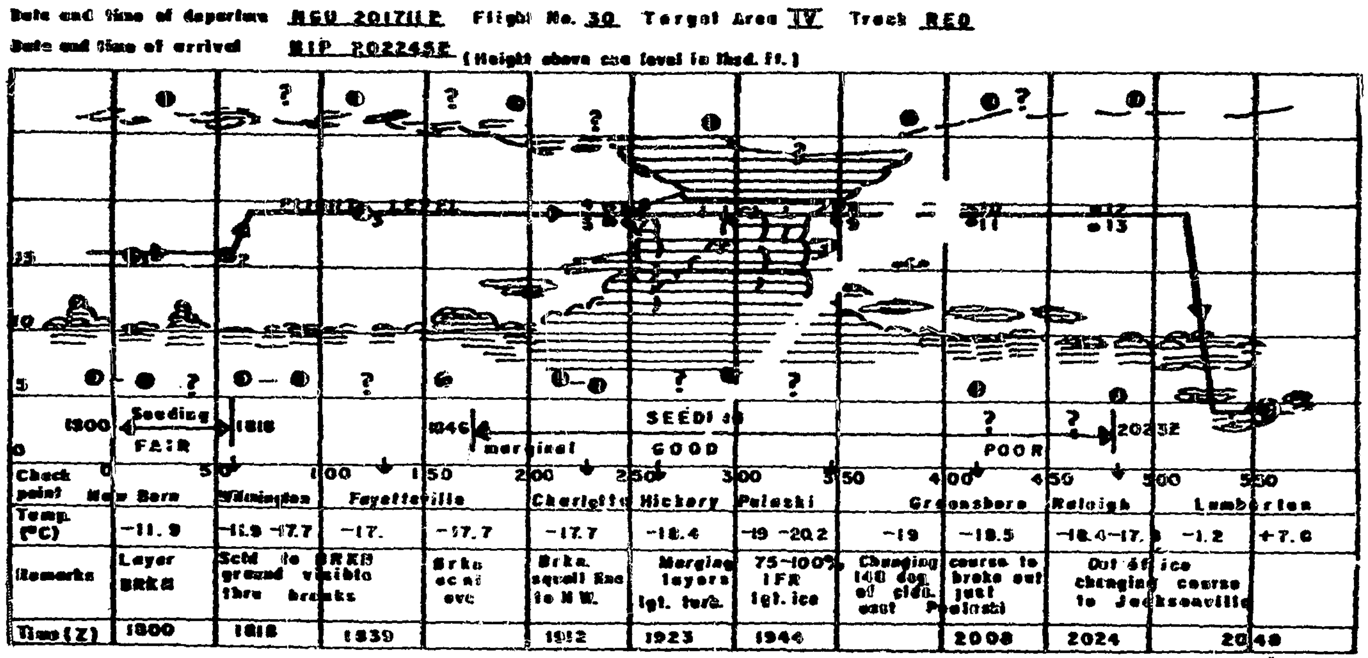

Fig. 35. Flight cross-section. Flight No. 30. Red track. 20 February 1954.

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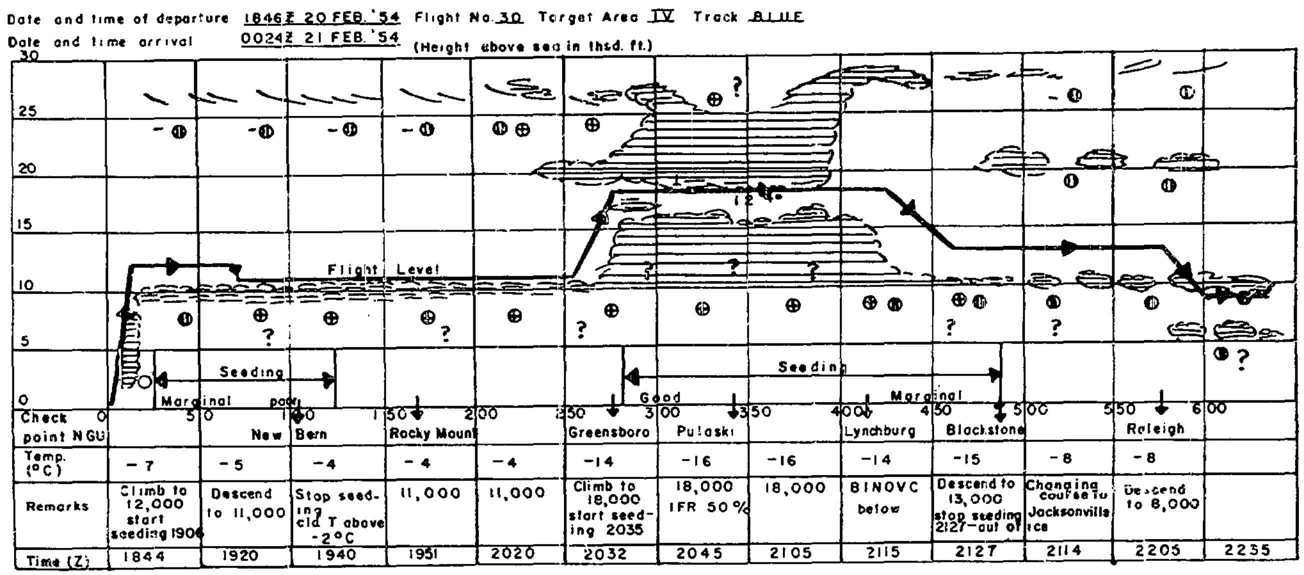

Fig. 36. Flight cross-section. Flight No. 30. Blue track. 20 February 1954.

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C. Ground seeding: Stations 1B and 1C terminated at 0100 Z and 0530 Z respectively.

D. Flight operations:

Red flight began seeding at 1800 Z at 16,000 feet. Remainder of flight was conducted at 19,000 feet. 1750 lbs. were dispensed in 105 minutes. Light icing was encountered in clouds.

Blue flight began seeding at 1906 Z at 12,000 feet. Flight was conducted at various altitudes in an effort to remain on top of clouds. 1600 lbs. of dry ice were dispensed in 86 minutes.

Green flight was cancelled because of mechanical difficulty.

10. Case No. 31, Baker (Figs. 37 - 38).

A. Zero hour: 1830 Z, 24 February 1954.

B. Target area: 2.

C. Flight operations:

Blue track was flown at 19,000 feet. Simulated seeding was conducted in clouds for 98 minutes. Light and moderate rime and clear ice was encountered in clouds at temperatures between -20 and -22° C.

11. Case No. 32, Able (Figs. 39 - 42).

A. Zero hour: 1230 Z, 26 February 1954.

B. Target area: 6.

C. Ground seeding: All stations operated on schedule.

D. Flight operations:

Red flight began seeding at 1307 Z at 17,000 feet. Light rime ice was encountered in clouds. 2000 lbs. were dispensed in 122 minutes.

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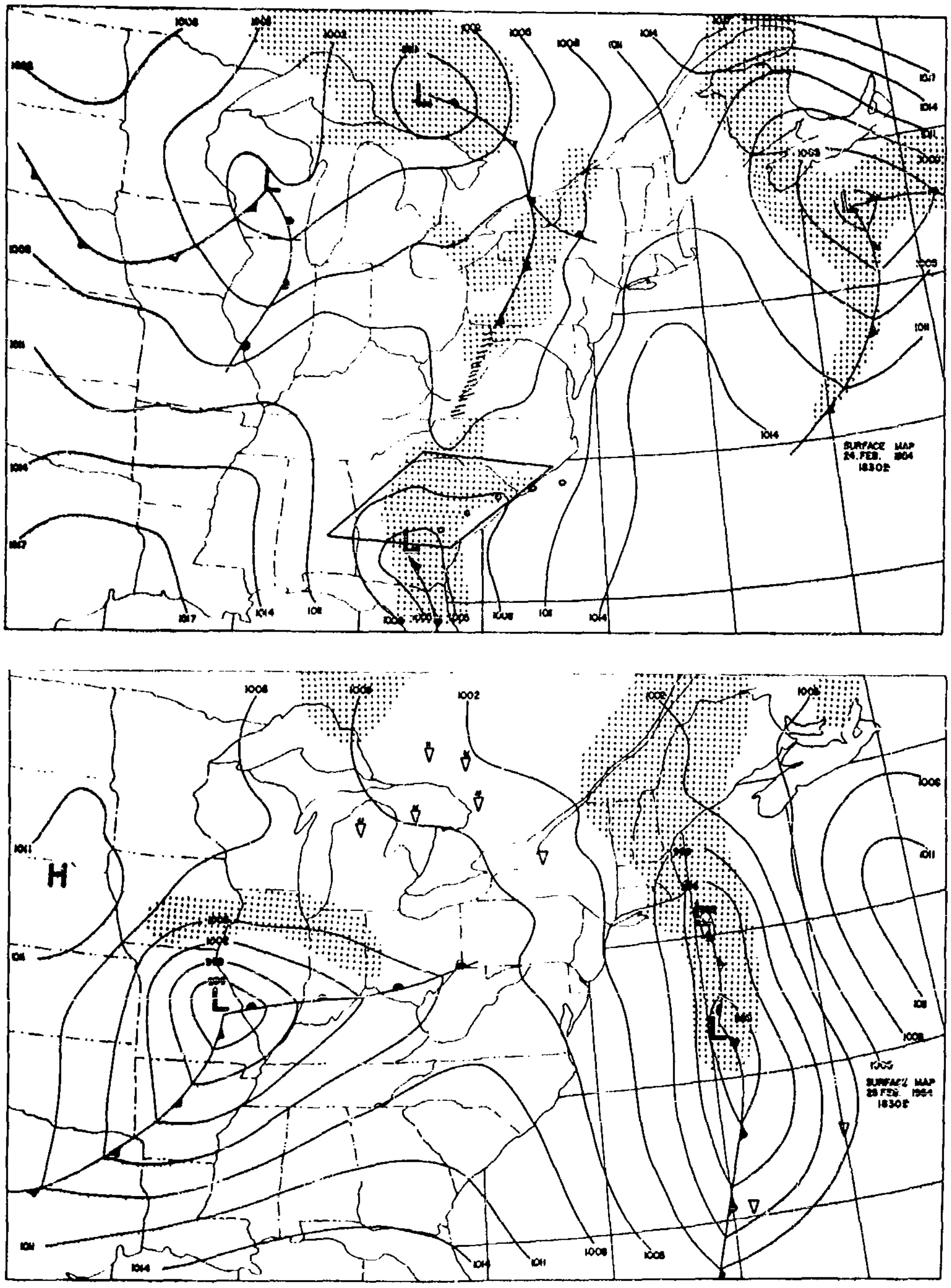

Fig. 37. Case No. 31. Zero hour: 1830Z, 24 February 1954. Baker.

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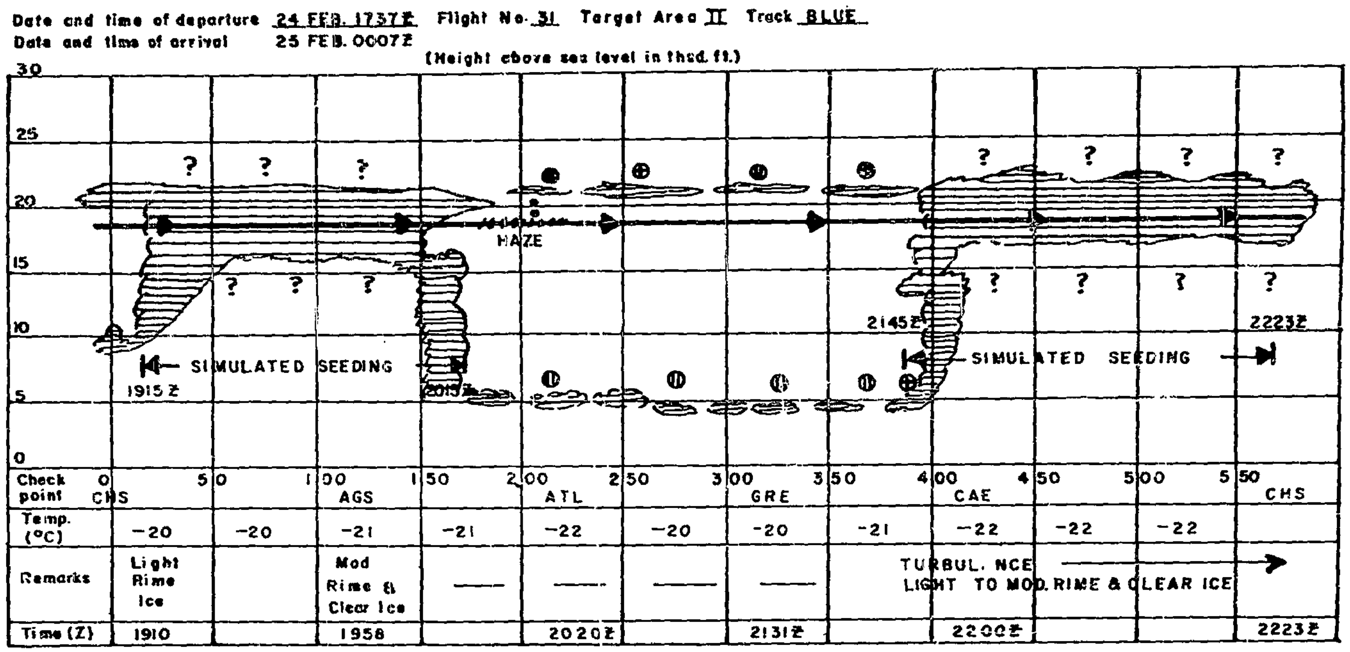

Fig. 38. Flight cross-section. Flight No. 31. Blue track. 24 February 1954.

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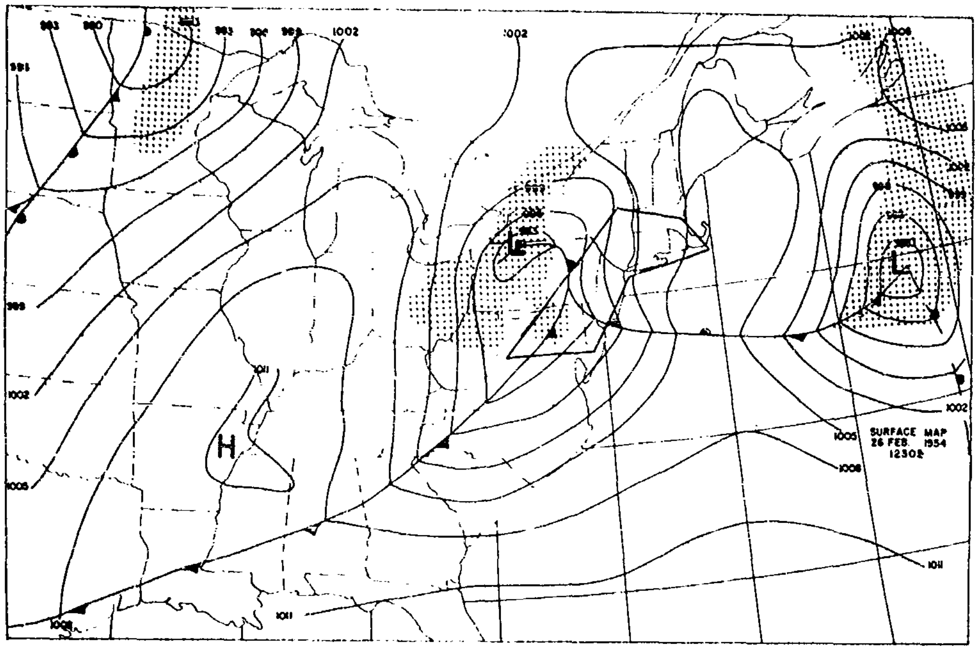

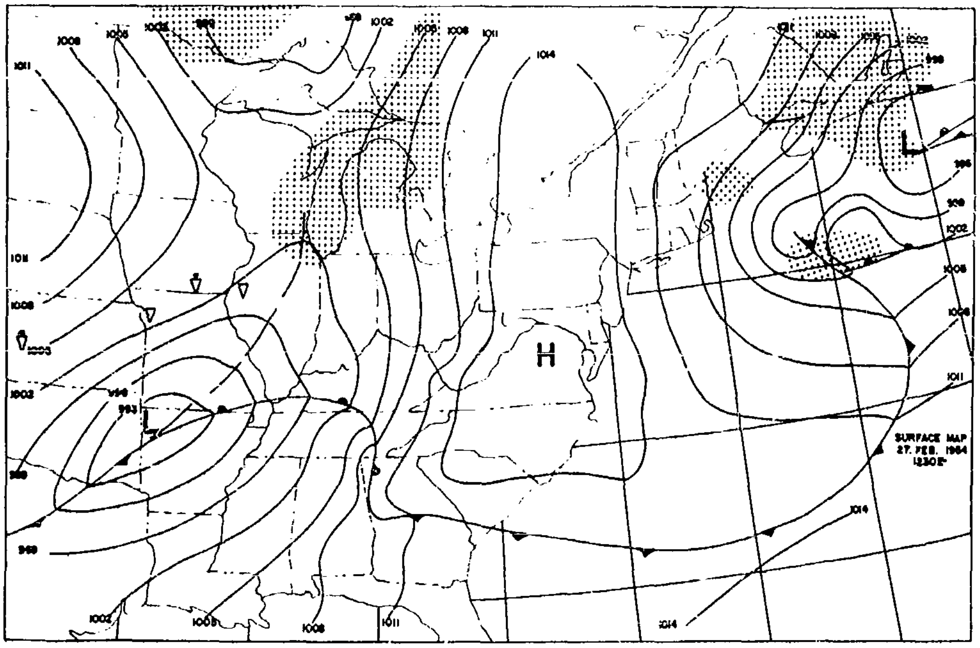

Fig. 39. Case No. 32. Zero hour: 1230Z, 26 February 1954. Able.

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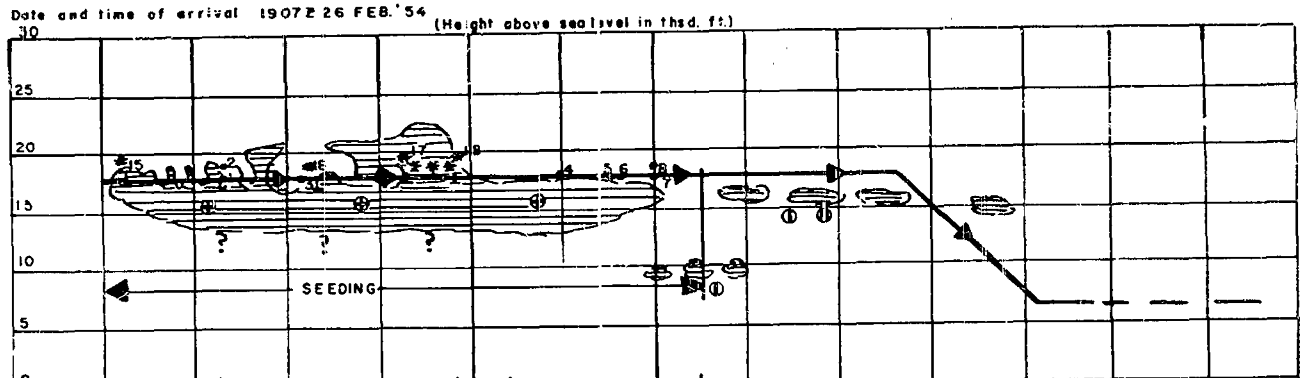
Date and time of departure 1219Z 26 FEB.'54 Flight No. 32 Target Area VI Track RED

Date and time of arrival 1907Z 26 FEB.'54



Check point	0 Quartico	50 Lisbon	100 Harrisburg	150 Boothwyn	200 Millville	250	300 Coles Point	350	400	450	500	550	600
Temp (°C)	−25.1°	−25.2°	−24.3°	−24.1°	−22.9°	−22.8°	−23.1°						
Remarks	17000' Light Rime 50% IFR	17000' Light Rime 50% IFR	17000' Light Rime in clouds	17000' Snow & Light Rime 100% IFR	17000' in tops ocnly 500' on top	17000' in tops ocnly 500' on top	17000' Mostly clear ovr Coles Pt.						
Time (Z)	1305	1323	1339	1357	1415	1445	1509						

Fig.40. Flight cross-section. Flight No. 32. Red track. 26 February 1954.

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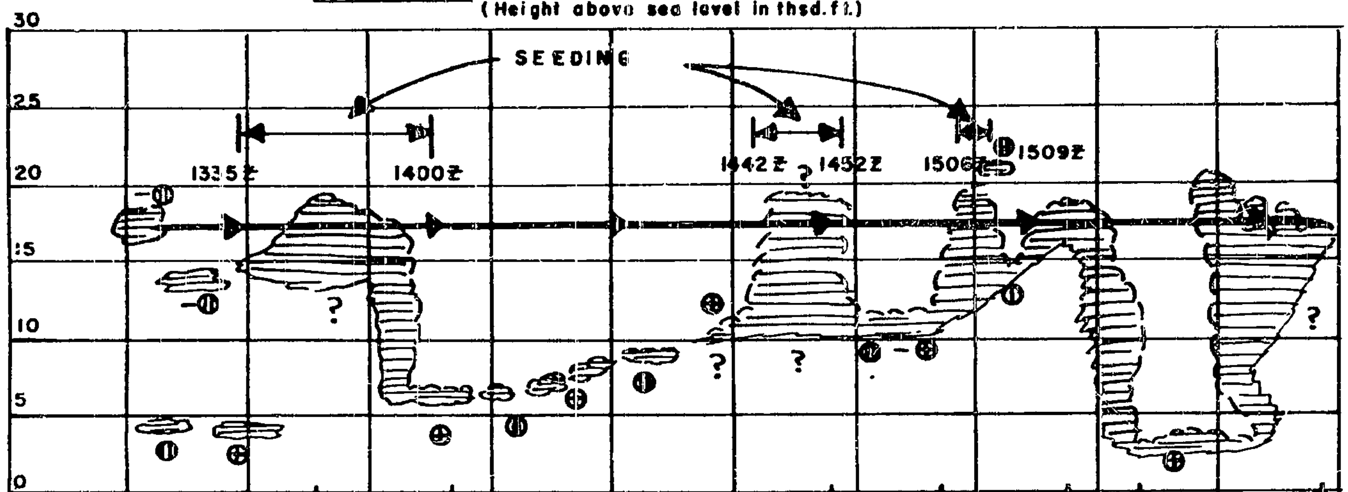
Date and time of departure 261228Z Flight No. 32 Target Area VI Track BLUE
Date and time of arrival 26 FEB.2045Z



Check point	MIV	LRP	ABL	AVP		POU	BDR	HEM	AMB	MIV
Temp. (°C)	−17	−20	−20	−21	−22	−22	−22	−22	−21	−20
Remarks	Con Trail in Thin Clouds	Mod Conf. Turb.	Hazy	In the Clear	Hazy solated Buildups	Thick Clouds	Thin	Light Rime	—	Thick Clouds
Time (Z)	1322	1345	1403	1425		1450	1503	1527	1540	1620

Fig. 41. Flight cross-section. Flight No. 32. Blue track. 26 February 1954.

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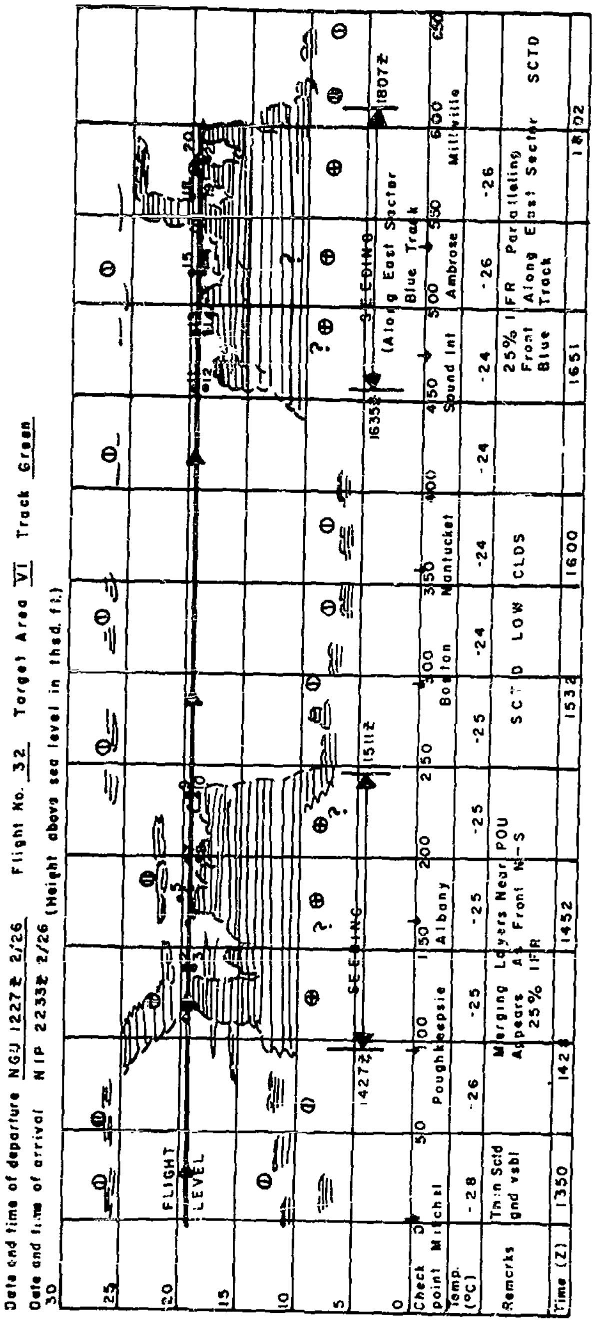

Fig. 42. Flight cross-section. Flight No. 32 Green track. 26 February 1954.

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Blue flight was conducted at 18,000 feet. Seeding began at 1335 Z. 1575 lbs. were dispensed in 38 minutes. Apparently the dispenser was not operating properly and the dispensing rate was about 12 lbs. per mile. Light rime was reported in cloud tops.

Green flight dispensed 2250 lbs. in 136 minutes at 19,000 feet beginning at 1427 Z. Some cloud modification was observed following the seeding (see Chapter III for further details). The last part of the seeding operation was conducted along the eastern sector of the Blue track due to the paucity of clouds on the Green track. No icing was reported.

12. Case No. 33, Baker (Figs. 43 - 44).

A. Zero hour: 1230 Z, 1 March 1954.

B. Target area: 6.

C. Flight operations:

Blue flight was conducted 5000 feet on top of clouds at altitudes between 9500 and 10,500 feet. Temperatures at flight level were never below -1° C. Although simulated seeding was carried out for 60 minutes, seeding conditions were sub-marginal on Blue track at the time of the flight.

13. Case No. 34, Able (Figs. 45 - 47).

A. Zero hour: 1830 Z, 13 March 1954.

B. Target area: 5.

C. Ground seeding: With the exception of station 40, which terminated at 2345 Z, all stations operated on schedule.

D. Flight operations:

Red flight was conducted in clouds and snow at 17,000 feet.

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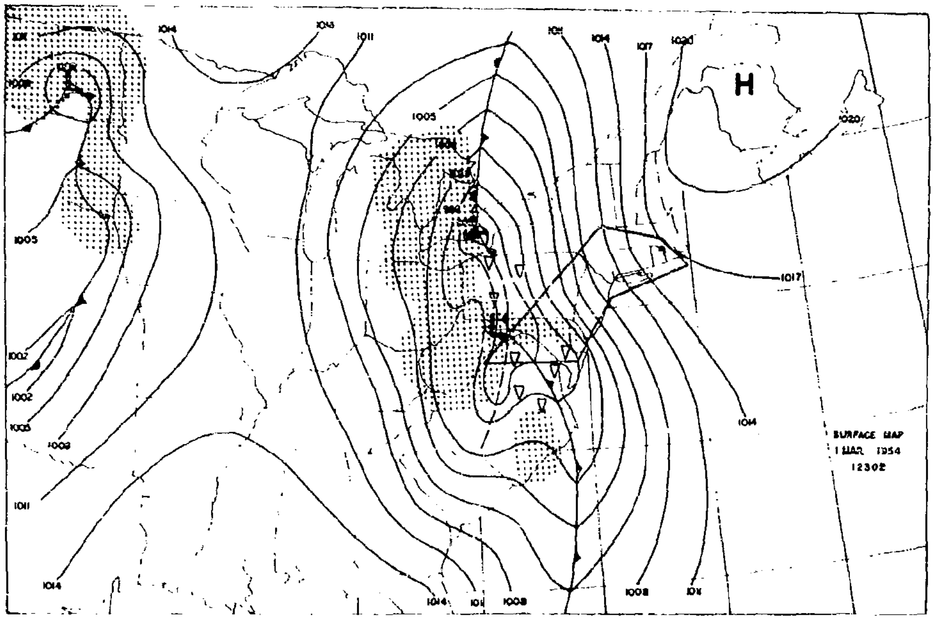

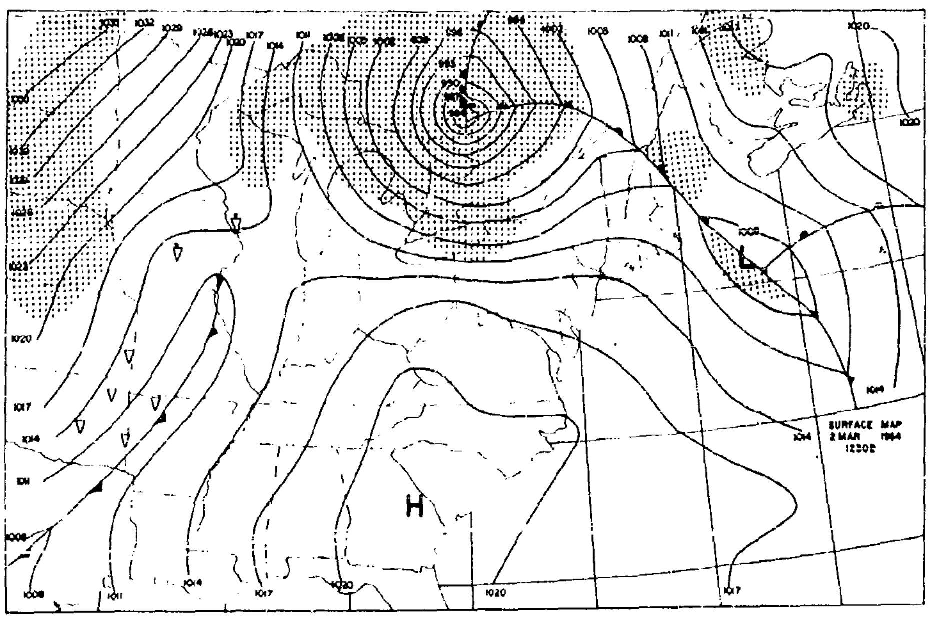

Fig. 43. Case No. 33. Zero hour: 1230Z, 1 March 1954. Baker.

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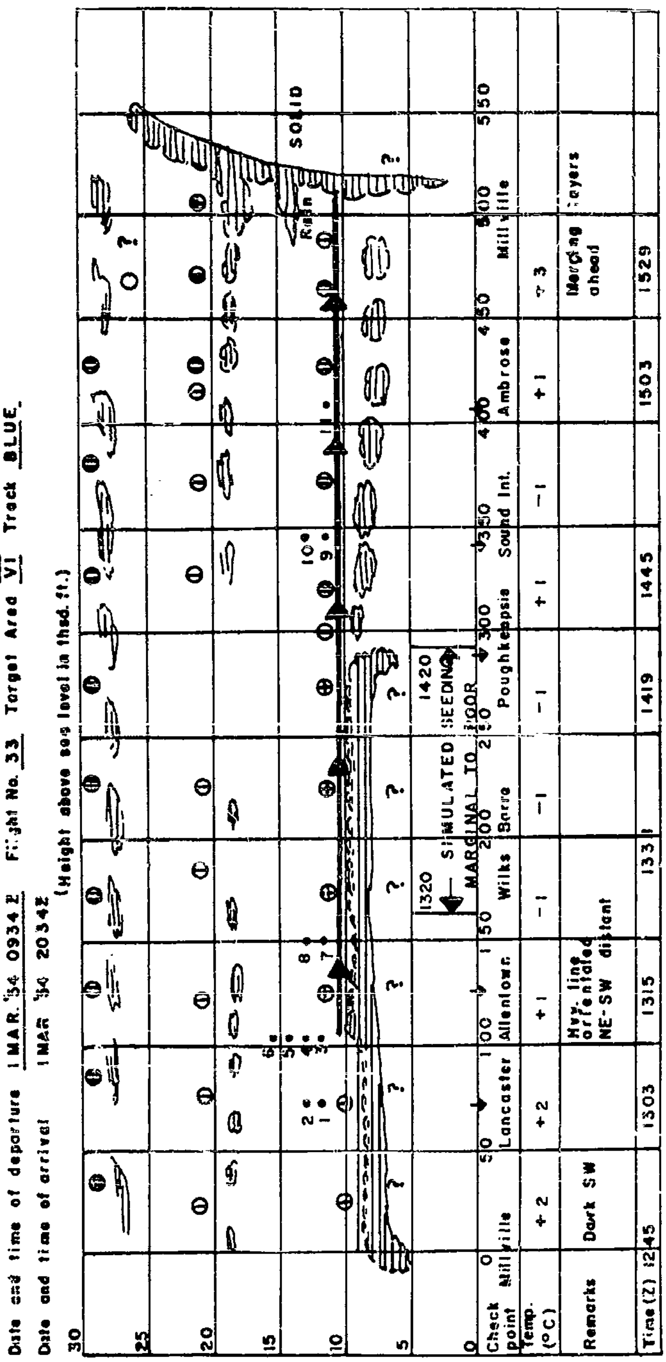

Fig. 44. Flight cross-section. Flight No. 33. Blue track. 1 March 1954.

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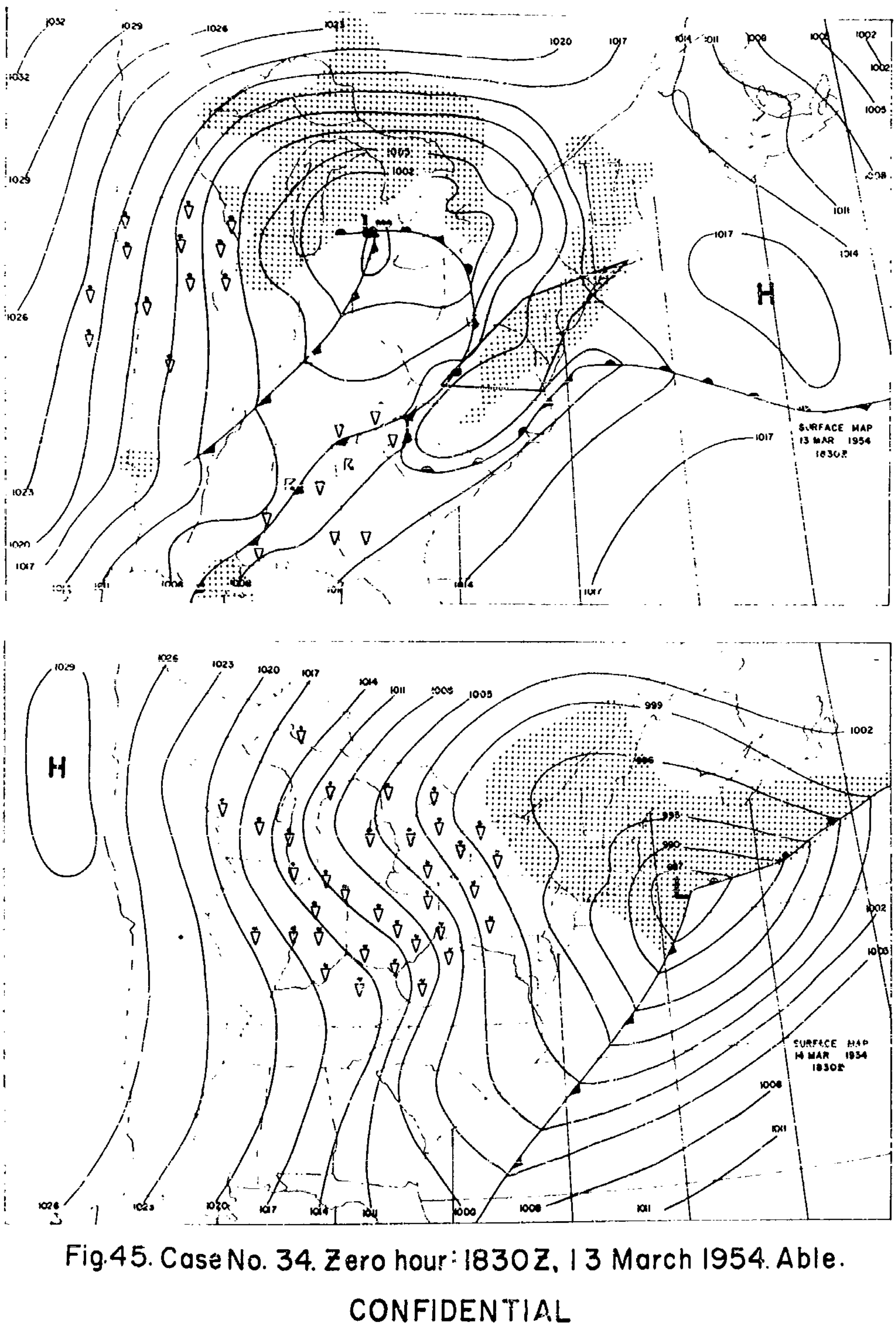

Fig.45. Case No. 34. Zero hour: 1830Z, 13 March 1954. Able.

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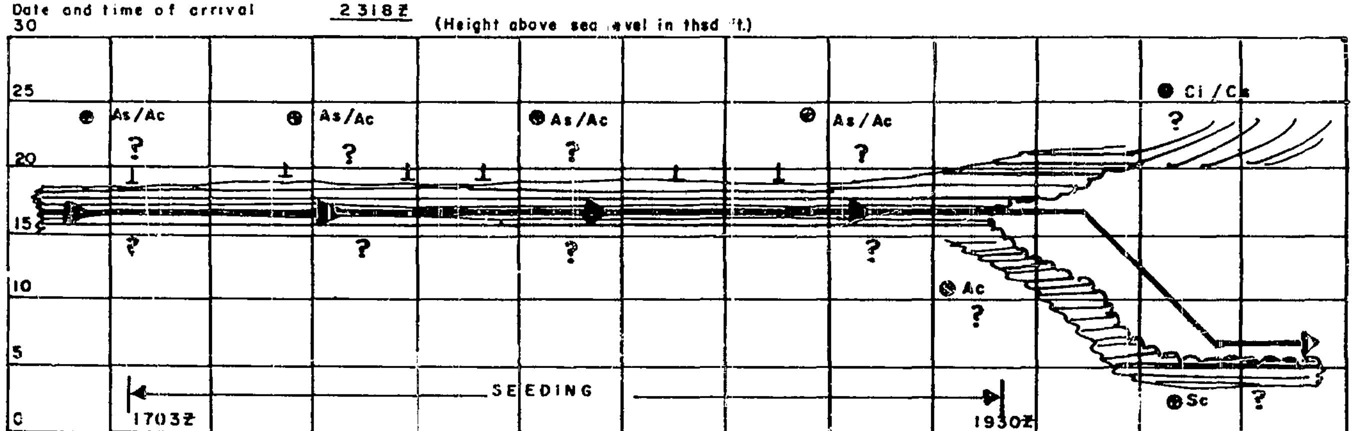
Date and time of departure 13 MAR 54 1417Z Flight No 34 Target Area V Track RED

Date and time of arrival 2318Z

(Height above sea level in thsd ft.)



Check point	0–50 Norfolk	50–100 Blackstone	100–150 Lynchburg	150–200 Roanoke	200–250 Abeam Lynchburg	250–300 Gordonsville	300–350 Quantico	350–400 Sharps	400–450 Norfolk	450–500	500–550	550
Temp. (°C)	-12	-11	-12	-12	-12	-12	-12	-12	-12			
Remarks	17000 Commence Ops. 1703Z	17000 Mod Snow at 1750Z	17000 Med. Snow	17000 Snow Stopped 1815Z	17000	17000 Mod. Snow at 1847Z	17000 Snow Stopped 1900Z	17000	17000 Ceased Ops. 1930Z			
Time (Z)	1655	1738	1810	1827	1838	1851	1903	1921	1940			

Fig. 46. Flight cross-section. Flight No. 34. Red track. 13 March 1954.

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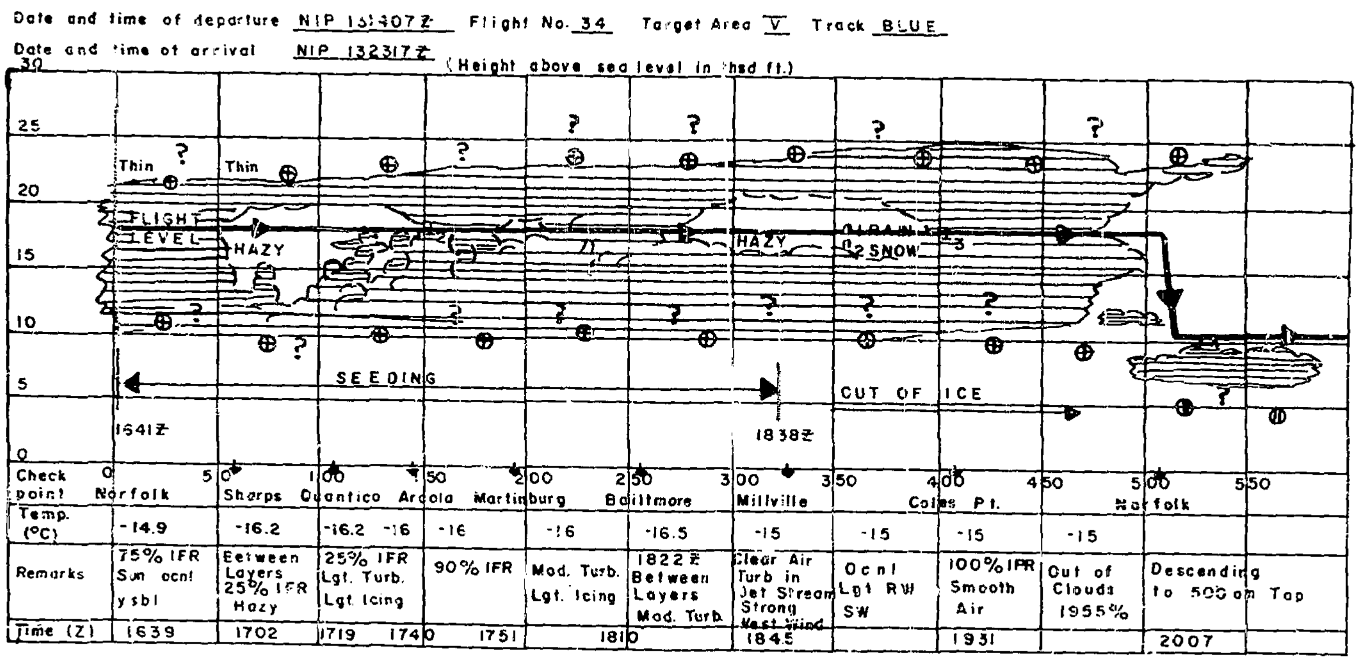

Fig. 47. Flight cross-section. Flight No. 34. Blue track. 13 March 1954.

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Seeding began at 1703 Z and 2050 lbs. were dispensed in 147 minutes.

No icing was reported.

Blue flight was assigned to an altitude of 13,000 feet and began seeding at 1641 Z. 2010 lbs. were released in 117 minutes. Light icing was experienced in clouds.

Green flight developed engine trouble over Richmond and returned to Jacksonville without dispensing in the assigned area. For reasons of safety, the load of 2050 lbs. of dry ice was released in clouds at a temperature of -12° C. between Richmond and Lumberton (in area 3).

14. Case No. 35, Baker (Fig. 48).

 A. Zero hour: 1830 Z, 19 March 1954.

 B. Target area: 3.

 C. Flight operations:

 The Blue flight was aborted due to engine trouble over Savannah before reaching the area.

15. Case No. 36, Baker (Figs. 49 - 50).

 A. Zero hour: 1230 Z, 30 March 1954.

 B. Target area: 6.

 C. Flight operations:

 Blue flight was assigned to an altitude of 18,000 feet. Simulated seeding was carried out for 126 minutes. Light rime icing was encountered in clouds.

16. Case No. 37, Able (Figs. 51 - 54).

 A. Zero hour: 0630 Z, 28 April 1954.

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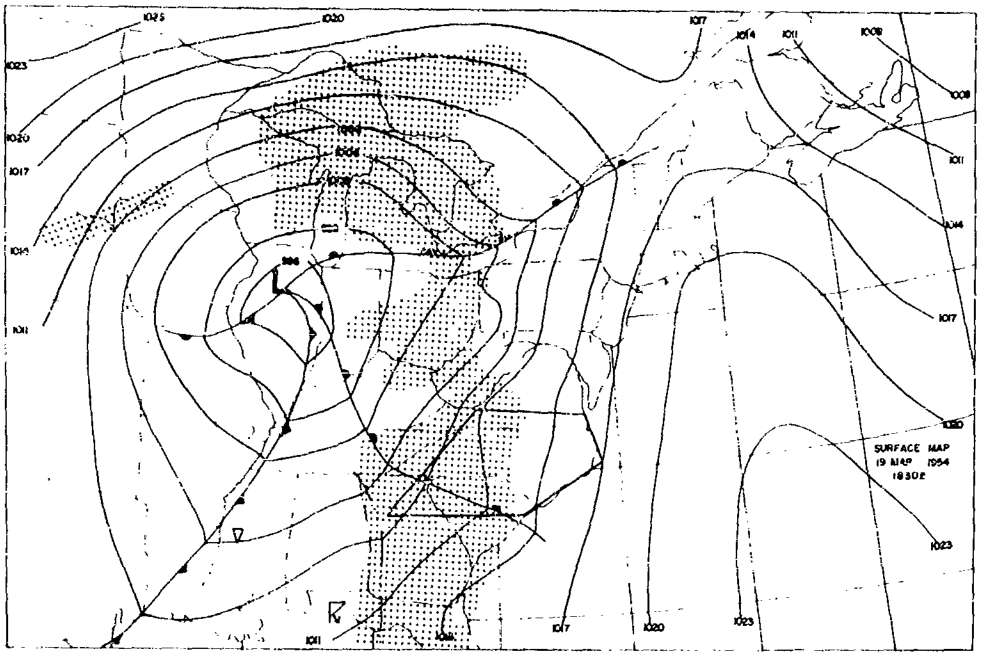

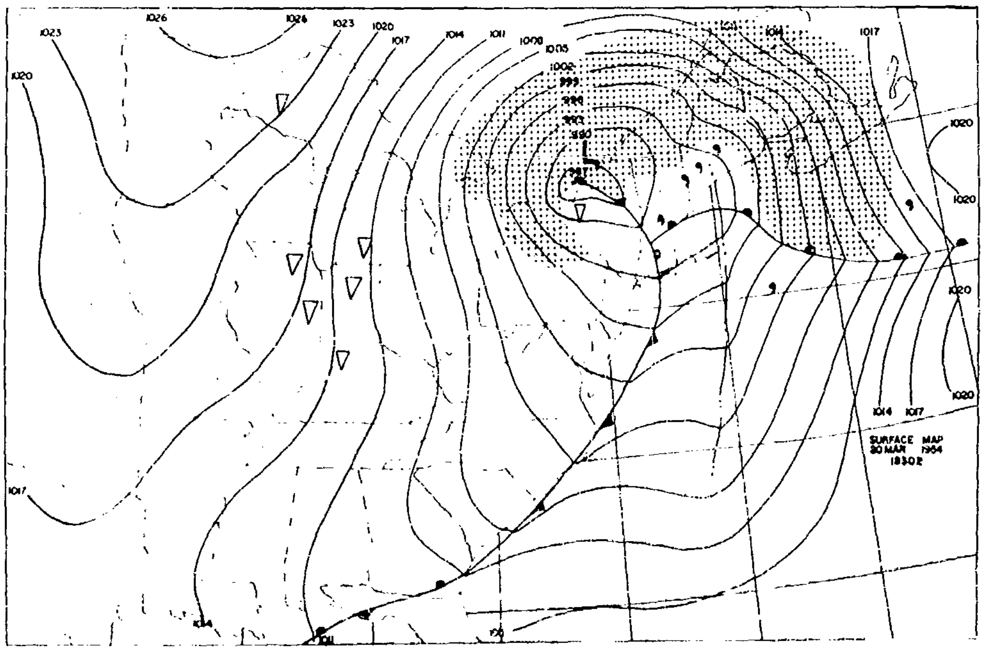

Fig. 48. Case No. 35. Zero hour: 1830 Z, 19 March 1954. Baker.

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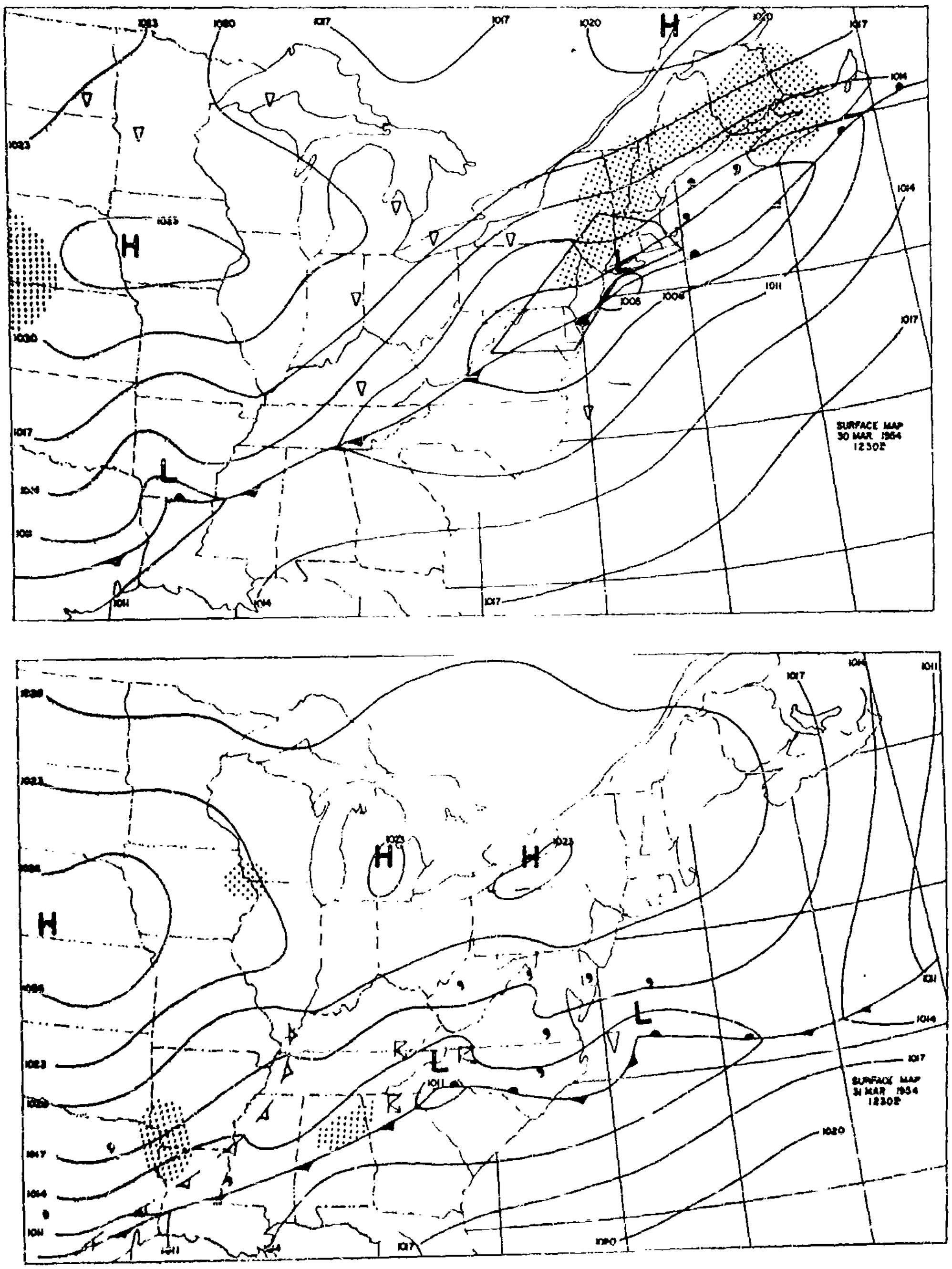

Fig. 49. Case No. 36. Zero hour: 1230 Z, 30 March 1954. Baker.

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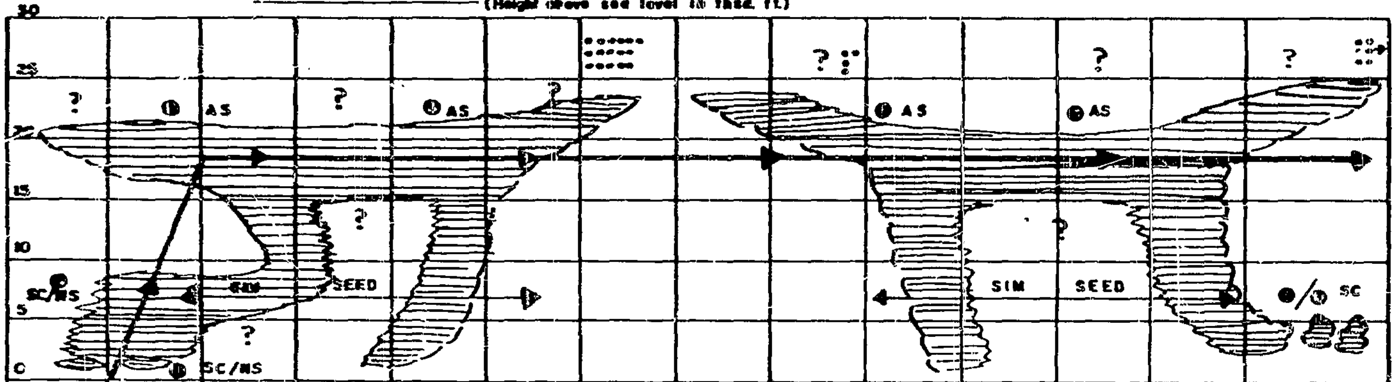
Date and time of departure KORVA 3-30-54 1101Z Flight No. 36 Target Area VI Track BLUE

Date and time of arrival JAX 3-30-54 1849Z (Height above sea level in thsd. ft.)



Check point	0 Norfolk	50 Patuxent R.	100 Salisbury	150 Millville	200 Wilmington	250 Lancaster	300 Allentown	350 Wilkes Barre	400 Middletown	450 Poughkeepsie	500 Bridgeport	550 Ambrose Lt.	600 Millville
Temp (°C)	See Seeding	−13	−14	−15	−15	−15	−16	−18	−18	−18	−15	−15	15
Remarks	Climb Had Rain In Lower Clouds	Wind: 230/60				Wind: 270/85						Wind: 260/90	
Time (Z)	1101	1134	1142	1203	1215	1235	1248	1313	1322	1332	1347	1422	1455

Fig-50. Flight cross-section. Flight No.36. Blue track. 30 March 1954.

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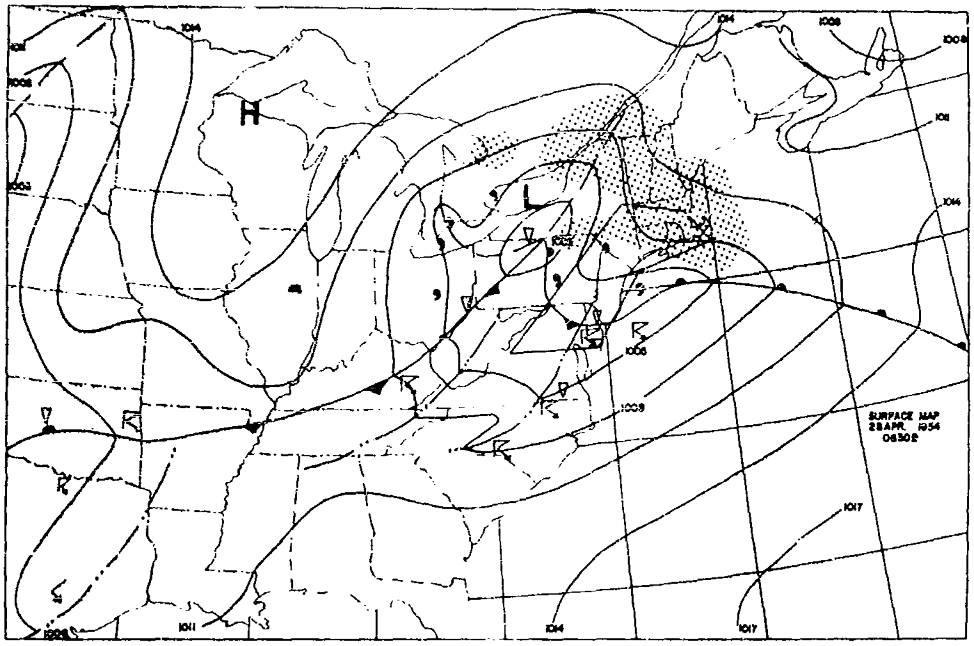

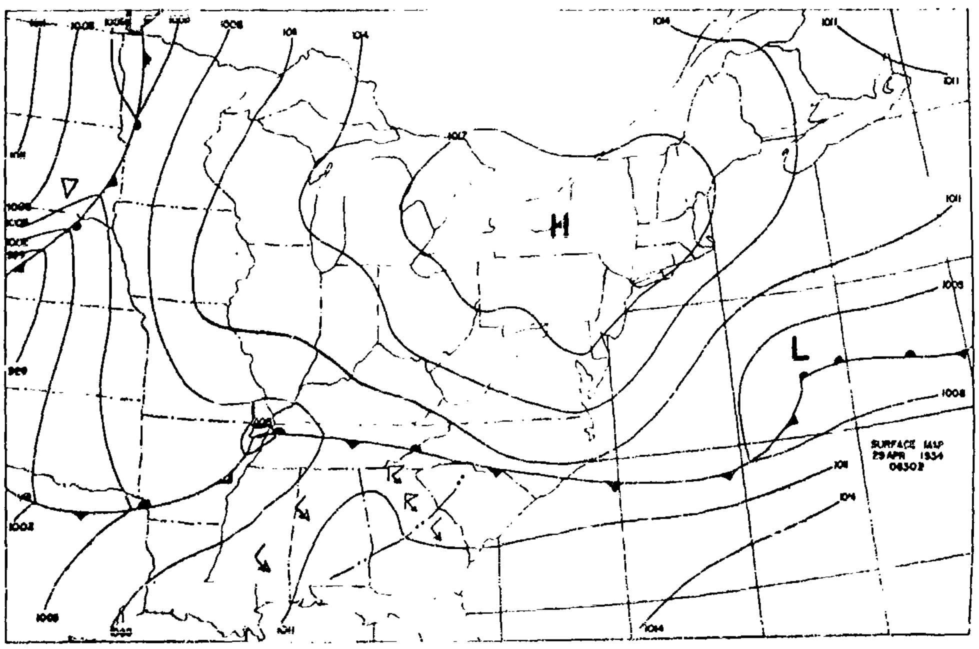

Fig. 51. Case No. 37. Zero hour: 0630Z, 28 April 1954. Able.

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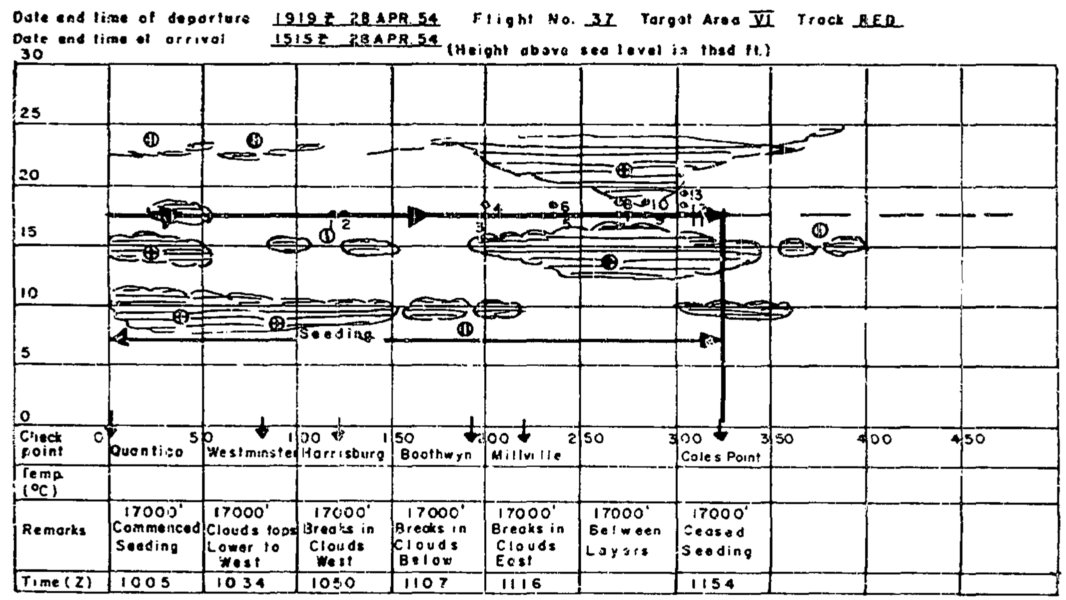

Fig. 52. Flight cross-section. Flight No. 37. Red track. 28 April 1954.

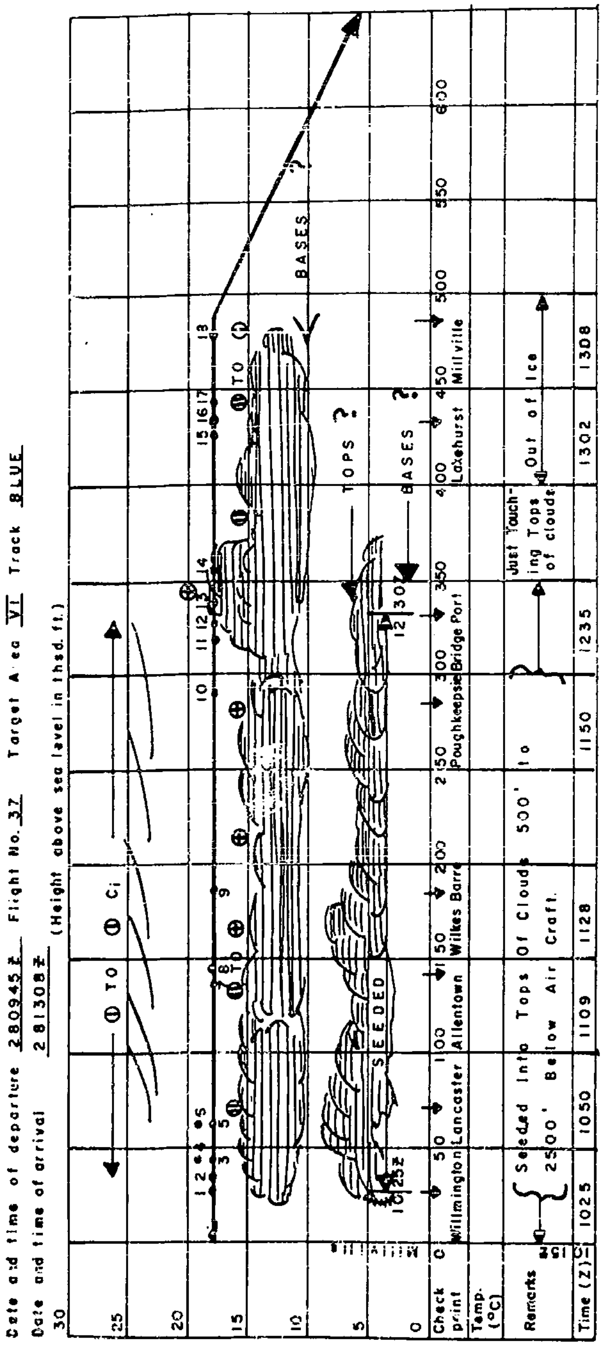

Fig. 53. Flight cross-section. Flight No. 37. Blue track. 28 April 1954.

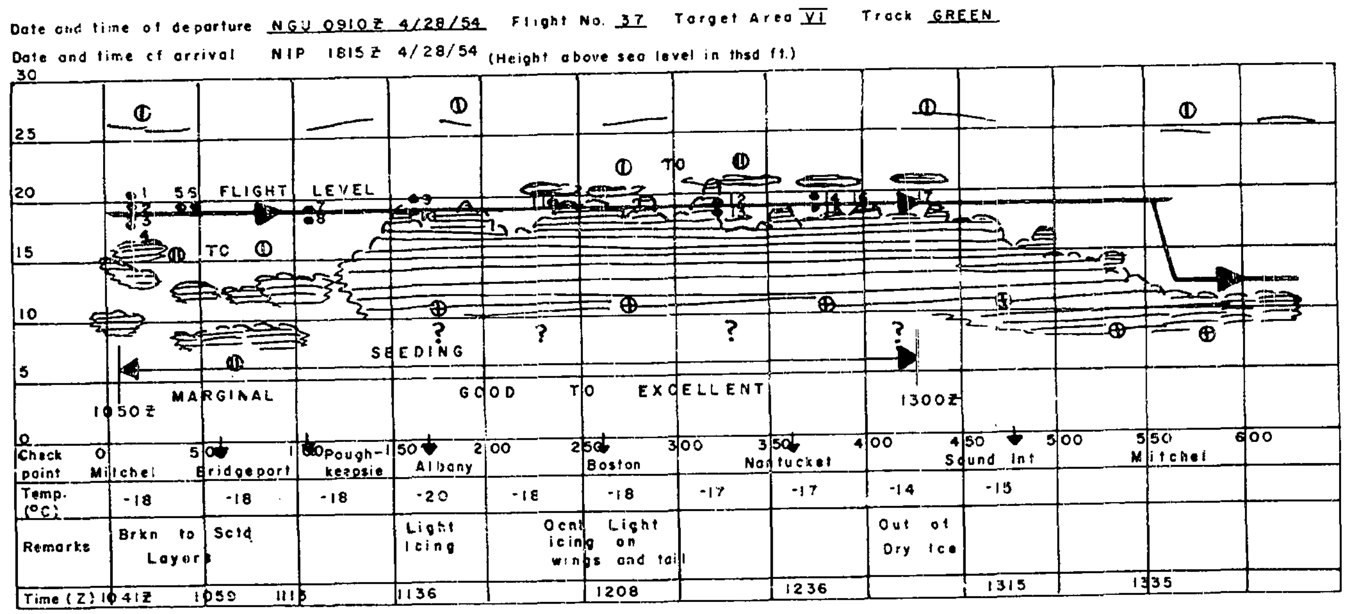

Fig. 54. Flight cross-section. Flight No. 37. Green track. 28 April 1954.

B. Target area: 6.

C. Ground seeding: Stations 1B and 4A terminated at 1230 Z and 1400 Z respectively. Stations 5A began operating at 0730 Z. 5B began at 0530 Z and terminated at 1700 Z. All other generators operated on schedule.

D. Flight operations:

Red flight dispensed 1750 lbs. in 109 minutes at 17,000 feet beginning at 1005 Z. No temperature measurements were obtained due to failure of the thermometer.

Blue flight commenced seeding at 1025 Z at an altitude of 18,000 feet. Thermometer was inoperative. 2250 lbs. were dispensed in 125 minutes.

Green flight was assigned to 19,000 feet where seeding was begun at 1050 Z. Occasional light rime ice was reported at temperatures between -18 and -20° C. 2200 lbs. were dispensed in 130 minutes.